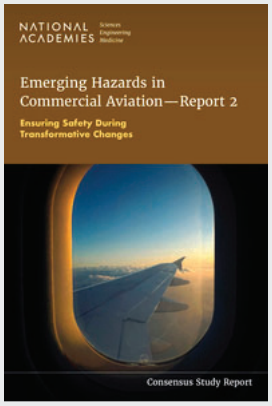
Exhibit 3



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Emerging Hazards in Commercial Aviation—Report 2

Ensuring Safety During Transformative Changes

Committee on Emerging Trends in Aviation Safety

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This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft before its release. The review of this report was overseen by **CHRIS HENDRICKSON (NAE),** Carnegie Mellon University, and **CRAIG PHILIP (NAE),** Vanderbilt University. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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This report was developed under the overall supervision of Thomas R. Menzies, Jr., Director of Consensus and Advisory Studies, Transportation Research Board (TRB). Lida Beninson, Senior Program Officer, TRB, served as the study director. She and Stephen Godwin, Scholar, TRB, assisted the study committee in the preparation of this report. Dylan Rebstock provided support for report development. Daniel Talmage provided liaison with the National Academies of Sciences, Engineering, and Medicine's Board on Human-Systems Integration. Claudia Sauls and Timothy Marflak of TRB provided support to the committee in arranging meetings.

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Preface

I write this preface from the 2024 Experimental Aircraft Association Air Venture gathering in Oshkosh, Wisconsin, a great annual event in aviation. I am struck here by the dichotomy it captures—the value of historical experience (as the old guard shares with the new all their insights on the classic technologies underlying so much of present-day aviation) juxtaposed with the spirit of innovation (shown by all the new things being demonstrated overhead as I type).

This report is written within this tension between the security of the known and the potential for innovation. In the closing chapter of our first report (NASEM, 2022), our committee identified several major potential sources of stress on commercial aviation safety, presenting both challenges and opportunities. These include new technologies, new business models and new entrants who are not steeped in the same knowledge and culture underlying aviation safety.

Our focus in this report is on transformative changes to technology and operations, which we define as those representing such a step-change that current methods for assessing and managing safety cannot be simply tweaked or extrapolated. We stepped back to examine how and where safety of transformative changes can and needs to be addressed, using the existing safety management principles recommended by the International Civil Aviation Organization as a framework. This framework includes (1) the safety-risk management inherent to designing, evaluating, certifying and approving new technologies and operations, (2) the safety assurance process of continually monitoring operations for any possible safety concern, and (3) the aspects of organizational structure and culture that can drive an organization's ability to support safety in all its aspects.

To learn from the community, we held two workshops that engaged representatives of the Federal Aviation Administration (FAA), those proposing transformative changes to technology and operations, and the aviation safety community. The agendas of these workshops appear in Appendix B. We continued our efforts by engaging with current and former representatives of FAA and experts in safety culture.

Finally, we are grateful for the comments of independent peer reviewers and their perspectives and improvements to the report, whose names were unknown to the committee during the review process.

Amy R. Pritchett, *Chair*
Committee on Emerging Trends in Aviation Safety

REFERENCE

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Acronyms and Abbreviations

AAM	advanced air mobility
ADS-B	Automatic Dependent Surveillance-Broadcast
AIM	Aeronautical Information Manual
AIS	autonomous and intelligent systems
ASIAS	Aviation Safety Information Analysis and Sharing
ASRS	Aviation Safety Reporting System
ASTM	American Society for Testing and Materials
ATO	Air Traffic Organization
AVS	Office of Aviation Safety (FAA)
CAST	Commercial Aviation Safety Team
CFR	Code of Federal Regulations
ConOps	Concept of Operations
DA/DH	decision altitude or decision height
DAA	Detect and Avoid
EFVS	enhance flight vision system
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FDM	Flight Data Monitoring
FOQA	Flight Operations Quality Assurance
GM	General Motors
GPA	glide path angle
GPS/GLONASS	Global Positioning System/Globalnaya Navigatsionnaya Sputnikovaya Sistema
IAEA	International Atomic Energy Agency
IFP	instrument flight procedure
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	Inertial Navigation System
JO	Job Order
LORAN	long range navigation

LOSA	Line Operations Safety Audit[1]
MASPS	Minimum Aviation System Performance Standards
MOPS	Minimal Operational Performance Standard
MPS	minimum performance standard
MRO	maintenance, repair, and overhaul
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NEA	Nuclear Energy Agency
NISA	Nuclear and Industrial Safety Agency
NTSB	National Transportation Safety Board
OCI	Organizational Culture Inventory
ODA	Organizational Designation Authorization
OEM	original equipment manufacturer
OIG	Office of Inspector General
OSED	Operational Services and Environment Definition
PMA	Parts Manufacturer Approval
RNP	Required Navigation Performance
RTCA	Radio Technical Commission for Aviation (a standards body now known by its acronym)
RVR	runway visibility range
SA	safety assurance
SAS	Safety Assurance System
SMICG	Safety Management International Collaboration Group
SMS	safety management system
SRM	safety risk management
STC	Supplemental Type Certification
sUAS	small unmanned aerial system
TERPS	Terminal Instrument Procedures
TSO	Technical Standard Order
UAS	unmanned aircraft system
VLOS	Visual Line of Sight
VSRP	Voluntary Safety Reporting Program

[1] LOSA is referred to as "Line Operation Safety Assessment" in some documents by the Federal Aviation Administration.

Executive Summary

In compliance with a directive in Section 132 of the Aircraft Certification, Safety, and Accountability Act of 2020,[2] the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine tasked a study committee with identifying, categorizing, and analyzing emerging safety trends in air transportation, including offering advice to Congress, the Federal Aviation Administration (FAA), industry, and others on options for improving means for identifying, monitoring, understanding, and addressing emerging aviation safety risks. Throughout its activities, the committee relies on a definition of "emerging" that refers to something "becoming apparent or prominent." Thus, the committee interprets emerging trends in safety to include both new hazards emerging via proposals for new technologies or operations, as well as current concerns that may be evolving to become prominent. This report marks the second installment of a series of six reports to be issued within a span of 10 years.

This report focuses on safety management for new entrants and for transformative changes to technologies and operations that cannot simply just apply current methods. "Transformative changes" are defined here as changes that are sufficiently novel that their impact on safety and risk cannot be extrapolated from current data and analysis methods. Such changes are highlighted in the potential systemic stressors noted in the first report with "new entrants" and "new technologies and operations."

This report frames its analysis using the established principles applied in aviation safety management. Safety management occurs across the entire lifecycle of technologies and concepts of operation, from their design, through their implementation via production, operations, and maintenance. Such safety management spans multiple processes, including (1) safety risk management processes before new technologies and operations are implemented, to identify hazards, assess their risk, and implement appropriate safeguards and mitigations, largely focusing on certification and regulatory approval before implementation; (2) safety assurance processes once new technologies and operations are implemented via ongoing data collection and analysis to support continuous improvement; (3) safety policy and objectives determining the high-level properties of the organization integrating a commitment to safety; and (4) safety promotion across all levels of the organization.

First, the committee examined how to identify and address emerging safety concerns via safety risk management with transformative changes to technology and operations. Second, examining safety assurance, the committee noted that, while extensive data gathering activities support monitoring of current concerns, gaps exist in data and analysis methods for predicting new hazards that may emerge with transformative technologies and operations; similarly, methods for predicting and then continuing to monitor for safety concerns are vital to the safe implementation of transformative changes to technology and operations. Third, examining safety policies and promotion across the organization, the committee noted in its first report how

[2] H.R.8408, 116th Cong. (2019–2020). Aircraft Certification Reform and Accountability Act. https://www.congress.gov/bill/116th-congress/house-bill/8408.

FAA's assessment of its internal safety culture was then in a formative state requiring further development and review. In this report the committee follows up on the present status of FAA's safety culture assessment and extends this discussion to the question of how to foster and monitor the safety cultures of organizations across the industry.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Safety Risk Management

The starting point for managing aviation safety must be during design of new technologies and operations and continue through their testing and evaluation before implementation. Known as safety risk management, this discipline includes appropriate processes for identifying hazards, assessing their risk, and implementing appropriate safeguards and mitigations commensurate with risk; these are critical contributions to identifying, categorizing, and analyzing emerging safety trends in aviation. FAA plays three vital roles in safety risk management:

1. Certification of individual products, personnel and practices of designers, producers, maintainers, and aircraft operators (managed by the Office of Aviation Safety [AVS]);
2. Establishing the collective Operating and Flight Rules and procedures by which aircraft are operated within the National Airspace System (NAS) (managed by AVS and Air Traffic Organization [ATO]);
3. Deployment, operation, and maintenance of the air traffic management system (new equipment, operations, and procedures) that provide aircraft separation, air traffic control and air traffic management (managed by the ATO).

Proposals for certifying transformative changes poses a unique challenge when current methods of demonstrating compliance do not sensibly describe their characteristics. Literal adherence to the existing regulations may unnecessarily complicate any attempt at certification or suggest workarounds that do not necessarily support safety. FAA's role should be viewed as ensuring an acceptable level of risk while at the same time providing a reasonable path for innovation within the broad intent of safety risk management. (F2-1)[3]

Recommendation 2-1: The Federal Aviation Administration Office of Aviation Safety should evaluate current regulations, guidance, and standards to determine if they limit or preclude certification of transformative changes in technologies and commensurate changes in personnel, production, and operating certificates, or appear to disincentivize new features that may enhance safety in different ways than historically assumed. Where such a situation is found, certification processes and standards should be updated to promote effective safety risk management within these new developments, including collaboration with industry where appropriate.

Similarly, the committee found that, for most types of operations, the FAA AVS does not currently have mechanisms for comprehensive safety risk management that spans the different

[3] Findings as they appear in the chapters are denoted herein at the end of each paragraph as F(chapter number-finding number), or 2-1 in this case.

FAA organizations certifying technologies, personnel, and operating certificates, and governing the general operating and flight rules for the NAS. Since the regulatory offices are organized around how the NAS operates today, transformative changes can be difficult, if not impossible, to address. (F2-2)

Recommendation 2-2: The Federal Aviation Administration should establish cross-cutting positions, staffed by officials responsible for examining proposed transformative changes that simultaneously seek to manage safety and risk by purposeful, integrated changes to technologies, personnel, and operating certificates, and authorized to identify suitable means of compliance for, and certify, such transformative changes based on their collective mitigation of risk.

Current standards for certification and operational approval for many functions necessary for safe flight prescribe technologies, roles, and skills for personnel, and operating rules that assume historic concepts of operations and architectures. These assumptions do not fit with, and can conflict with, proposed transformative changes to aviation technology and operations. Instead, performance-based standards can direct assessments of how well a proposed technology or operation meets safety standards and do so in a manner directly supporting certification and operational approval. (F2-3)

Recommendation 2-3: The Federal Aviation Administration Office of Aviation Safety should lead the definition of performance-based standards for flight-critical functions that allow for different equipage, different methods of performing the functions, and a different distribution of who or what is performing the functions' constituent activities, including changes in distribution of activity between human or machine, on the aircraft or on the ground, by the operator (e.g., airline), air traffic or a third party. These performance-based standards should be developed to the point that they can serve as a basis for certification and for approving new operations within the National Airspace System.

The committee also found challenges beyond certification of individuals' products and operating procedures: radical transformations to general operating and flight rules are being proposed, or will be necessary to safely operate proposed vehicles. However, there are no systematic, rigorous, broadly documented methods for identifying, categorizing, and analyzing the risks that may emerge with novel operating and flight rules, especially where the changes are sufficiently transformative that they cannot be predicted via extrapolations from the current day. (F2-4)

Recommendation 2-4: Congress should ensure that fundamental and generalizable research is chartered to establish a systematic and repeatable framework for analyzing and designing civil aviation general operating and flight rules that enable novel technologies and operations to share the airspace with current operations. This requires fundamental and generalizable research beyond the Federal Aviation Administration's current research expertise and portfolio, and may need the support of other agencies conducting fundamental research into operational system-wide safety. These methods must calculate the appropriate performance

requirements for all the functions noted earlier, be able to identify and characterize safety concerns created or mitigated by the operating and flight rules, and be detailed enough to articulate the specific activities, and required information needs and control authority, of all actors and stakeholders and how these activities combine to create safe operations.

Likewise, different operators cannot use conflicting general operating and flight rules in the same airspace, highlighting that these flight rules cannot be developed independently by individual applicants, but must have some guiding structure and constraints that are fair to all in terms of access to the airspace and safety for all in the airspace while minimizing undue constraints on innovation. (F2-5)

Recommendation 2-5: The Federal Aviation Administration (FAA) and the aviation industry should develop a process for defining the general operating and flight rules that enable new, innovative operations to coexist in the airspace with other innovative operations as well as legacy operations. FAA should launch a single-purpose group (e.g., task force, aviation rule making committee) including representatives of all relevant stakeholders from legacy and new operations for the purpose of identifying the fundamental structure of and constraints on operating and flight rules for broad classes of current and proposed new operators in the National Airspace System. This should include consensus-based recommendations for development of technical standards that characterize all relevant aspects of the proposed operations relevant to assessing their safety and that identify the essential constraints on and performance measures of new operating rules needed to address potential risks emerging from changes in the operations.

Safety Assurance

Even after the most rigorous safety risk management process, safety concerns may continue to emerge as a system is implemented and operated. Some concerns may only become apparent in real operations. Other concerns may only be very subtle and require more experience and data to identify and characterize. Furthermore, new concerns may arise over years or decades as a technology or operation that had been "safe" becomes stressed by changes in the operating environment and other external factors.

Thus, the second component of safety management, *safety assurance*, depends on the on-going collection and analysis of data, both to understand possible concerns and to constantly monitor for the unexpected. Furthermore, safety assurance is only truly effective if it not only monitors safety performance but also uses its insights to both direct and manage change within an organization, and to reflect upon, and continuously improve, safety management overall.

The committee found that proposed transformative changes in technology and operations provide both challenges and opportunities to rethink the appropriate data to collect to support safety assurance. Given that many new technologies can record a wide range of new measures, the opportunity exists to systematically determine what potential data streams best monitor for potential safety concerns that may emerge with innovation. When addressing this opportunity, the safety assurance process should particularly consider the unique safety concerns with changing roles of human and machine, and with the unique concerns with monitoring software-

intensive functions. This should also capitalize on criteria used in certification and approval of transformative changes, including monitoring of criteria applied earlier in certification and other safety risk management processes based on performance-based standards and on special criteria and conditions. (F3-1)

Voluntary safety reporting programs (VSRPs) are a vital data source in safety assurance, given the ability of personnel throughout the NAS to detect and describe anomalies. Changing roles between human and machines, particularly with increasingly automated functions and remotely piloted aircraft, may impact human observability of safety concerns. In such cases, the personnel expected to provide VSRP reports, and the questions they are asked within the report, may need to change. Likewise, further digital data may be required to make up for gaps in, and to make sense of, VSRP reports. (F3-2)

Recommendation 3-1: The Federal Aviation Administration Office of Aviation Safety should determine the process and criteria by which an applicant can demonstrate that their proposed data set is appropriate for safety assurance when implementing transformative changes in technology and operation. This determination should be sufficiently proactive to identify where new sensors and recording mechanisms need to be built into systems during their design and certification to then enable safety assurance during their operation. These data sets can leverage the criteria used in safety risk management (including certification and operational approval) to demonstrate safety of their new attributes through performance-based standards and through the special conditions and criteria.

Given the many forms of data analysis enabled by fields such as data mining and machine learning, more and better is possible in both characterizing and predicting known (or hypothesized) safety concerns, and monitoring for the unknown. Unfortunately, little research has been conducted and documented in the public domain on how such methods of data analysis can be applied to the full range of analysis that aviation safety assurance requires. The committee knows of no recent research by federal agencies. Likewise, the sensitive nature of aviation data, and the absence of publicly available data sets, has limited open research into the extension of general data analysis methods to aviation.

Extensive data analysis methods have been established in other domains and industries suitable for expanding the capabilities of aviation safety assurance. These methods particularly span the needs of transformative changes to technologies and operations, where simple definitions of exceedances cannot span the open questions in possible safety concerns that need to be monitored for; instead, transformative changes require a range of methods, from those suitable for monitoring for, characterizing and predicting potential concerns to detecting the unknown. (F3-3)

Recommendation 3-2: The Federal Aviation Administration Office of Aviation Safety should determine the process and criteria by which an applicant can demonstrate that their proposed data analysis methods are appropriate for safety assurance when implementing transformative changes in technology and operation, and that they are appropriate for the data set being collected. This determination should specifically support both (1) characterizing phenomena that are only hypothesized or poorly understood as a result of transformative changes; and (2)

monitoring for situations and conditions that are unknown and statistically abnormal, and thus should be flagged for further evaluation.

Safety Culture

Organizational processes and culture are critical aspects of effective safety management. The committee examined several aspects of safety culture. They first examined the annual safety culture assessment by the FAA AVS. Second, because other safety critical industries, particularly nuclear power, have begun to explore the safety culture of regulators and its effect on operators, the committee examined how the constructs of regulatory culture may apply to AVS. Finally, the committee examined strategies FAA could use to ensure that industry organizations—especially "new entrants"—develop and actively maintain and shape mature safety cultures.

Examining the FAA AVS safety culture survey and assessment, the committee supports the AVS shift in 2023 to a survey based on the 10 International Atomic Energy Agency (IAEA) safety culture traits and its efforts to improve the response rate. The appointment by AVS of a manager with experience in the safety culture assessment process is appropriate. These steps represent good progress, although the committee observes that the congressional request for the annual assessment of the AVS safety culture was enacted in December 2020, while the second survey had been completed at the time of the committee's briefing in March 2024, the overall second annual assessment was incomplete. (F4-1)

A safety culture survey represents but the initial step in an ongoing dialogue and discovery process between senior management and employees about the safety culture of an organization and how it can be strengthened. For the committee to carry out its charge of reviewing AVS's annual safety culture assessment requires greater insight into the steps being taken by AVS to assess its culture beyond the survey and how it is using what it is learning to strengthen the AVS safety culture. (F4-2)

Success in strengthening the AVS safety culture depends heavily on the direct, visible, and frequent engagement of senior AVS management with front line employees in enabling, enacting, and elaborating the AVS safety culture. These are not responsibilities that can be delegated to the manager responsible for the safety culture survey. At the time of this writing, the committee lacks evidence about such a level of engagement by the highest levels of AVS management in learning from safety culture assessment and implementing actions aimed at strengthening AVS's safety culture. (F4-3)

The emerging concept of the safety culture appropriate for a regulator reflects the view of the IAEA that, if regulators expect the organizations that they regulate to have good safety cultures, they must understand and model safety culture principles and behaviors themselves. To date there is insufficient research in defining, and distinguishing between, the traits and behaviors of the safety cultures of regulators and the safety culture of those they oversee. The emerging concept of regulatory safety culture is one that AVS can monitor and learn from. Moreover, FAA could support the development of this concept and its assessment through its research budget. (F4-4)

The safety culture of any large organization does not change quickly. An annual survey is too frequent to pick up shifts in employee perspectives about the organization's safety culture. (The Nuclear Regulatory Commission conducts a survey every 3 to 5 years.) The ongoing assessment process of the AVS safety culture can also employ appropriate cycles of other

processes, such as focus groups, ongoing dialogue with front-line employees, and input from the employee voluntary reporting system to help AVS articulate and mature its safety culture. (F4-5)

Recommendation 4-1: Congress should continue requiring that the Federal Aviation Administration Office of Aviation Safety (AVS) assess its safety culture, but allow AVS the flexibility to reduce the frequency of the safety culture survey, and in alternate years allow AVS to focus more of its annual assessment efforts on formal and informal communication by leadership, conduct of focus groups and other forms of dialogue with employees about their perceptions of AVS's safety culture, and feedback to employees about what leadership is learning through the assessment process and the changes it is making in response. Within this process, AVS should identify two or three major goals the organization has in strengthening its safety culture and a short list of actions it will be taking in the next assessment. Likewise, AVS should identify the safety culture traits and behaviors it should model as a regulator to the industry organizations it oversees.

Recommendation 4-2: The safety culture assessment manager that Federal Aviation Administration (FAA) Office of Aviation Safety (AVS) has added to its staff should report regularly to the AVS Associate Administrator and the FAA Administrator, both of whom should be responsible for appropriate actions to enable a strong, and continuously improving, AVS safety culture.

The committee also examined how FAA can monitor and respond to industry organizations' safety cultures. The components of safety management, the data they generate, and their implementation in a safety management system (SMS), can provide FAA with a primary mechanism for monitoring organizations' safety culture maturity, how safety management will be integrated into operations and management by new entrants, and how safety management can be applied throughout the organization for continual improvement. (F4-6)

Promising safety indicators to support both industry organizational structures and safety culture and FAA monitoring would include testing of employee competence in understanding and executing risk controls; feedback between front-line employees and system developers regarding identification and management of hazards; identification and response to unanticipated emerging hazards within the organization; assessments of employee voluntary reports, SMS audits, audit deficiencies, and corrective action plans and timeliness of response to them; and other indicators of the organizations' preoccupation with what might go wrong and continual improvement. (F4-7)

These findings on safety culture contribute to recommendations next for safety management that is integrated across disciplines, organizations, and the lifecycle of new products and operations.

Integrated Safety Management

The tasks of identifying, monitoring, understanding, and addressing emerging aviation safety risks cannot be fully achieved by only looking at separate aspects of the NAS and by applying sequential processes. Instead, safety is only effectively managed when all aspects of safety

management are purposefully coordinated, and when they integrated across the many organizations involved.

Looking specifically at managing safety across organizations, safety cannot be regulated by examining only the safety management processes of a prime organization that involves third-party suppliers or service providers in support of their design, production or aircraft operation; likewise, it is not sufficient for the regulator to oversee each organization separately. Instead, the prime organization's decision to involve others, including purchasing their products and services, requires a deliberate, layered approach to safety management that ensures all contributions together comply with their safety risk management and safety assurance processes, and are based on appropriate organizational processes and culture. The regulator has the role in overseeing that this layered safety management is implemented and continuously monitored and used to manage safety across all constituent organizations. (F5-1)

Recommendation 5-1: The Federal Aviation Administration Office of Aviation Safety should establish the personnel, mechanisms, and policies that enable oversight of effective layered safety management of an organization applying for certification, ensuring that this safety management also spans the contributions of those third parties whose products and services contribute to safety. This oversight must ensure that this layered safety management is not only implemented correctly at the time of initial certification but also continuously applied.

Often, the entities that seek to certify products, to certify personnel, and to operate and maintain aircraft are separate, uncoordinated organizations, and they may be active at very different points in time. Safety is bolstered when each entity, at the time of its activity, is expected to capture the data and knowledge that informs safety management by those reasonably expected to use the same technologies or operations after them. (F5-2)

Recommendation 5-2: The Federal Aviation Administration Office of Aviation Safety should identify and characterize the data and knowledge associated at each stage in designing, testing, maintaining, and operating aircraft that then can be useful to safety management in the life of the product or operation. This data and knowledge should be required to be captured at the time, and later integrated into subsequent activities in support of both safety risk management and safety assurance.

Recent events suggest that the FAA AVS may already be challenged to regulate all aspects of the NAS. Transformative changes will further pose challenges with managing new risks. To address both current and likely future technologies and operations will require adequate funding and staffing, and requires this staff has the requisite technical expertise across the full spectrum of technologies. Furthermore, AVS staff must have the training and vision to oversee broad safety management processes spanning the life of a product (design, production, and operation), spanning multiple organizations and considering the organization structures and culture needed in these organizations that they oversee. (F5-3)

Recommendation 5-3: The Federal Aviation Administration Office of Aviation Safety should evaluate its personnel requirements in light of the demands placed on

the workforce in identifying and addressing both existing and emerging risks. Emphasis should be placed on expertise required to oversee and evaluate new and emerging technologies and operations, to oversee the transition from safety risk management to safety assurance as new technologies and operations are implemented, to support the maturation of safety culture within the industry organizations it oversees, and to ensure rigorous safety management processes within all the contributing organizations that impact aviation safety.

Even when all is properly regulated and evaluated in best faith, any first-time implementation represents a new frontier in knowledge in which the unexpected can manifest subtly or suddenly and violently. In aviation, even reasonably small changes to otherwise-solid systems have a history of the unexpected occurring. Transformative changes in technology and operations reflect an even larger step-function change in the knowledge required to design systems and operations safely, and even to know what tests and monitoring to run. Each transformative change represents a step-change in knowledge—and each of these step changes may have gaps that are undetectable and inscrutable until later, with experience. Thus, it is important to constantly understand that, even after the best safety risk management before implementation, something unexpected may happen once something new takes flight.

Thus, the aviation industry, and FAA in all its roles, should remain vigilant for emerging safety risks as new technologies and operations are implemented—to detect the precursor before it manifests as an accident, to investigate unexpected behaviors and effects to characterize their safety and risk, and to be open-minded and prepared to seek new mitigations to newly identified risks. (F5-4)

1
Introduction

In compliance with a directive in Section 132 of the Aircraft Certification, Safety, and Accountability Act of 2020,[4] the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine tasked a study committee with identifying, categorizing, and analyzing emerging safety trends in air transportation, including offering advice to Congress, the Federal Aviation Administration (FAA), industry, and others on options for improving means for identifying, monitoring, understanding, and addressing emerging aviation safety risks. Throughout its activities, the committee relies on a definition of "emerging" that refers to something "becoming apparent or prominent." Thus, the committee interprets emerging trends in safety to include both new hazards emerging via proposals for new technologies or operations, as well as current concerns that may be becoming prominent. This report marks the second installment of a series of six reports to be issued within a span of 10 years.

The first report in this series was subtitled "Initial Assessment of Safety Data and Analysis Processes" and provided the committee's initial review of the major processes for detecting emerging trends in aviation safety in place in the United States (NASEM, 2022). It covered the range of data sources and analysis processes currently used to identify aviation safety hazards, as well as approaches for assessing safety culture for a regulatory body such as FAA. Following the release of the report, the committee offered an updated Statement of Task (see Box 1-1) to reflect their findings and discussions from the first year of the study.

BOX 1-1
Statement of Task

In response to a request from Congress, this project will "identify, categorize, and analyze emerging safety trends in air transportation." The committee will review data and analyses of all relevant sources of information, such as operational data being used by the Federal Aviation Administration (FAA) and the air transport industry to monitor for potential safety concerns; government and industry voluntary aviation safety reporting systems; FAA's annual safety culture assessment; and other sources the committee deems appropriate, including National Transportation Safety Board accident investigations; FAA investigations of accidents and incidents; air carrier incidents and safety indicators; and international investigations of accidents and incidents, including information from foreign authorities and the International Civil Aviation Organization. The committee will assess whether these available sources of information are being analyzed in ways that can help identify emerging safety risks as the aviation system evolves and whether other information should be collected and analyzed for this purpose, such as data on accident precursors. The committee may engage in its own empirical analyses of databases.

[4] H.R.8408, 116th Cong. (2019–2020). Aircraft Certification Reform and Accountability Act. https://www.congress.gov/bill/116th-congress/house-bill/8408.

The project will focus primarily on commercial air transportation sector, but will also include other current and prospective users of the national airspace system that could pose risks to commercial aviation. The committee will draw on the results of FAA's annual internal safety culture assessments and also advise the agency on data and approaches for assessing safety culture to ensure that FAA is identifying emerging risks to commercial aviation and sharing that information throughout the agency and with the public.

The project will produce an initial report in mid-2022, biennial reports through 2030, and a final report in 2031. It is expected that the committee's first report will include a high-level assessment of the efficacy of domestic public and private sources of data and information for identifying and assessing emerging risks and advise on data gaps that need filling. The first report is also expected to include the approach the committee intends to pursue in subsequent biennial reports to assess the robustness of domestic and international data sources and processes for analyzing them for the purpose of identifying emerging risks to commercial air transportation. In addition to documenting its study findings in each report, the committee may offer advice to Congress, FAA, industry, and others on options for improving means for identifying, monitoring, understanding, and addressing emerging aviation safety risks, including supplementing, improving, and harmonizing existing databases, reporting systems, and analysis methods.

ADDENDUM: During the second phase of the study to produce its first biennial report, the committee may employ a strategic foresight method, such as horizon scanning, to demonstrate alternative strategies for identifying emerging trends in aviation safety. While this exercise may reveal previously unidentified or overlooked hazards in commercial aviation, its primary aim will be to reveal whether such methods, including those that seek broad input from diverse parties, have the potential to be applied successfully for this purpose. The study committee is also expected to continue with its in-depth assessment of existing domestic and international data sources and analytic processes as means for identifying emerging risks to commercial air transportation.

For the second phase of this study, the specific items of the Statement of Task that are covered in this report include:

1. The committee will assess whether available sources of information are being analyzed in ways that can help identify emerging safety risks as the aviation system evolves and whether other information should be collected and analyzed for this purpose.
2. The committee will draw on the results of FAA's annual internal safety culture assessments and also will advise the agency on data and approaches for assessing safety culture to ensure that FAA is identifying emerging risks to commercial aviation and sharing that information throughout the agency and with the public.
3. The committee may employ a strategic foresight method, such as horizon scanning, to demonstrate alternative strategies for identifying emerging trends in aviation safety. While this exercise may reveal previously unidentified or overlooked hazards in commercial aviation, its primary aim will be to reveal whether such methods, including those that seek broad input from diverse parties, have the potential to be applied successfully for this purpose.

This report also addresses three conclusions named in the committee's first report. First, in its first report the committee noted how FAA's assessment of safety culture was, at the time of

the first report, in a formative state requiring further development and review, which is followed up on in Chapter 4 of this report. Second, the committee noted several potential systemic stressors on commercial aviation safety, including increasingly complex systems, new entrants in aviation, new business models, and the introduction of new technologies and operations; these stressors are manifold in transformative changes to technology and operations examined in this report. Third, the committee noted that, while extensive data-gathering activities support monitoring of current concerns, gaps exist in data and analysis methods for predicting new hazards that may emerge with new technologies and operations; similarly, methods for predicting and then continuing to monitor for safety concerns are vital to the safe implementation of transformative changes to technology and operations.

This report frames its analysis using the established principles applied in aviation safety management. Safety management occurs across the entire lifecycle of technologies and concepts of operation, from their design through their implementation via production, operations, and maintenance. Such safety management spans multiple processes, as summarized in Table 1-1: (1) safety risk management processes before new technologies and operations are implemented, to identify hazards, assess their risk, and implement appropriate safeguards and mitigations; (2) safety assurance processes once new technologies and operations are implemented via ongoing data collection and analysis to support continuous improvement; (3) safety policy and objectives determining the high-level properties of the organization integrating a commitment to safety; and (4) safety promotion across all levels of the organization.

TABLE 1-1 Safety Management Components and Elements

	Component	**Elements**
Predictive Processes (Chapter 2)	1. Safety Risk Management	Hazard identification
		Safety risk assessment and mitigation
Data Analytic Processes to Monitor and Improve Safety (Chapter 3)	2. Safety Assurance	Safety performance monitoring and measurement
		The management of change
		Continuous improvement of the SMS
Organizational Processes and Culture (Chapter 4)	3. Safety Policy and Objectives	Management commitment
		Safety accountability and responsibilities
		Appointment of key safety personnel
		Coordination of emergency response planning
		SMS documentation
	4. Safety Promotion	Training and education
		Safety communication

SOURCE: Adapted from ICAO, 2018, p. 9-2.

FAA has two critical roles in this safety management. First, FAA's Air Traffic Organization (ATO) operates the National Airspace System (NAS), including providing air traffic control and traffic flow management functions. Second, FAA's Office of Aviation Safety (AVS) is charged with ensuring aviation safety as the regulator that oversees safety risk management in a manner that does not unduly impede innovation and improvement in the industry and that is best positioned to convene industry-wide discussions of systemic issues.

Current mechanisms for safety management have evolved over decades to make commercial air transport the safest system ever. Many of these developments have been led by

the commercial air transport industry within the United States and internationally, to the point of establishing formal standards for safety management systems for air carriers, venues for data sharing and analysis, and an understanding of the fundamental attributes of safety culture. Other aviation sectors, such as regional airlines, helicopter operations, and general aviation are also increasingly adopting some aspects of safety management as appropriate to their specific attributes.

The first report identified a need for safety management for new entrants and for transformative changes to technologies and operations. "Transformative changes" are defined here as changes that are sufficiently novel that their impact on safety and risk cannot be extrapolated from current data and analysis methods. Such changes are highlighted in the potential systemic stressors noted in the first report with "new entrants" and "new technologies and operations." These can include remotely operated drones and new classes of aircraft, including small air taxi aircraft and transformative changes to aircraft such as new propulsion systems and ultra-efficient configurations. The committee examined how hazards might emerge from introducing transformative changes, how they can be predicted before implementation and then detected and mitigated during operation, and how the newly introduced technologies and operations can enable indicators of safety and risk that were not previously available before.

Furthermore, these transformative changes are often proposed by "new entrants" (i.e., companies without experience in aviation). These new entrants cannot all be assumed to be ready or prepared to thoroughly apply all aspects of safety management, including appropriate organizational processes to create a pervasive safety culture and building-in the capability to collect the data needed to monitor for safety through the lifecycle.

These transformative changes thereby create both challenges and opportunities for aviation safety management:

- New technologies have the challenge of requiring new predictive processes for safety risk management, including both identifying new hazards that they may create and understanding how they may disrupt current mitigations to omnipresent hazards, particularly during certification. An example includes proposed aircraft that are automated sufficiently to change the pilot's role to a higher-level of supervision carried out from a ground control station; methods of predicting and mitigating risks with the automated technology are still under debate, as is an understanding how the pilots' contribution to safety may change when no longer on the aircraft.
- New operations likewise have the challenge of requiring new predictive processes for safety risk management, including both identifying new hazards that they may create and understanding how they may disrupt current mitigations to omnipresent hazards. An example includes proposals for flight profiles that, through advanced sensing and computation, can execute high-density air traffic operations commensurate with urban air taxi operations; here, risks may arise both within the new operations and with others in the NAS acting under current operating rules.
- New technologies and operations could improve safety in a manner not accounted for in current standards. An example includes the technology to shift away from relying on "see and avoid" for conflict avoidance to sensor-based systems for "detect and avoid," which may be more accurate in detecting and avoiding conflicts.
- New technologies and operations simultaneously have the challenge of requiring, and the opportunity to enable, new mechanisms for collecting and analyzing the data

required to monitor and assure safety on an ongoing basis. An example includes, again, proposed automated aircraft. Current safety assurance assumes some degree of pilot detection and reporting of safety concerns that may no longer be possible for these aircraft, tempered by the potential capability for these automated systems to measure and capture new data streams not achievable with historic technologies.

- New entrants may have the challenge of coming from other industries and business models that do not have the organizational processes and culture needed for effective safety management at the levels demanded in aviation. Examples of different organization processes include those coming from other high technology industries that focus on moving to and through production quickly, without explicit organizational structures, policies and practices directed at safety.
- New entrants may represent the opportunity to implement the organizational structures, policies and practices that foster holistic safety management and the safety culture it requires. For example, expanded safety assurance processes may constantly highlight where and how new entrants need to improve their organizational processes and culture.

AVS's role as a regulator requires careful examination of proposals for transformative changes for two reasons. First, AVS cannot directly evaluate every design decision, supervise every action on the production line, and monitor all aspects of every flight. Instead, its role is to ensure that the organizations themselves have the correct safety management processes and safety culture. Transformative changes require AVS to evaluate the efficacy of new processes for safety risk management and safety assurance even when they are not easily accommodated by AVS's structure and extant regulations and guidance, and by current air traffic operations provided by ATO.

Second, AVS must consider the safety culture of the entities it oversees, including new entrants. This requires AVS to carefully consider their role and methods for monitoring safety culture, including how an organization's structure, policies and processes, and safety assurance methods, support continuous learning in support of safety. This also includes considering the culture appropriate for AVS to have within itself.

This report's chapters detail each of the components of safety management relative to transformative changes in aviation technologies and operations, and relative to new entrants. Chapter 2 covers safety risk management (SRM) and addresses whether potential hazards with transformative technologies and operations can be identified and mitigated through existing FAA certifications and operational approval processes, and through current mechanisms for updating the general operating and flight rules that govern the NAS. Chapter 3 discusses safety assurance (SA) and addresses methods and data for identifying and mitigating emerging hazards during the operations of transformative technologies, including the collection and analysis of safety indicators that have not been available before. Chapter 4 provides a broad discussion on safety culture and its assessment, which includes addressing FAAs annual internal safety culture survey and how FAA can use safety indicators generated through SRM and SA to determine new entrant safety culture maturity and monitor for emerging organizational and cultural hazards. Chapter 5 bridges the prior chapters through the concept of integrated safety management that spans multiple organizations and that better integrates the stages comprising the lifecycle of new technologies and operations (from design and testing with commensurate safety risk management, through implementation and operation with commensurate safety assurance).

Chapter 6 summarizes the findings of the report, highlighting recommended actions for FAA and for the industry.

REFERENCE

NASEM (National Academies of Sciences, Engineering, and Medicine). 2022. *Emerging Hazards in Commercial Aviation—Report 1: Initial Assessment of Safety Data and Analysis Processes*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26673.

2
Current Predictive Processes for Aviation Safety Risk Management Relative to Transformative Changes in Aviation Technologies and Operations

The starting point for managing aviation safety must be during design of new technologies and operations and continue through their testing and evaluation before implementation. Known as safety risk management, this discipline includes appropriate processes for identifying hazards, assessing their risk, and implementing appropriate safeguards and mitigations commensurate with risk; these are vital contributions to identifying, categorizing, and analyzing emerging safety trends in aviation. The Federal Aviation Administration (FAA) plays three vital roles in safety risk management:

1. Certification of individual products, personnel and practices of designers, producers, maintainers and aircraft operators (managed by the Office of Aviation Safety [AVS]).
2. Establishing the collective Operating and Flight Rules and procedures by which aircraft are operated within the National Airspace System (NAS) (managed by AVS and Air Traffic Operations [ATO]).
3. Deployment, operation and maintenance of the air traffic management system (new equipment, operations and procedures) that provide aircraft separation, air traffic control and air traffic management (managed by the ATO).

This chapter focuses on the safety risk assessment processes for which FAA's AVS organization is responsible, namely, oversight of those operating in the NAS, reviews how these processes are conducted and assesses their capability to provide safety risk management (SRM) for transformative changes in aviation technologies and operations.

SUMMARY: FAA PROCESSES FOR CERTIFICATION

To better understand FAA's current processes for certifying technologies, flight operations, operators, and personnel, the committee invited testimony from current and former representatives from FAA and examined the "parts" of the 14 Code of Federal Regulations (CFR) defining current processes.[5]

There are five main categories of FAA certificates and approvals needed to operate an aircraft commercially in the NAS:

[5] "Parts" here refer to the parts of Chapter 1 of CFR Title 14 "Federal Aviation Regulations," which defines classes of aircraft operators and establishes the standards that each must apply.

- **Certification for Products and Articles:** Under the purview of regulation 14 CFR Part 21, type certification includes the approval of new aircraft, engines, and propellors, which may then be incrementally updated through Supplemental Type Certifications (STCs). The regulations define a number of categories, each with more detailed regulations covering their airworthiness standards, including Part 23 for Normal Category Airplanes, Part 25 for Transport Category Airplanes, Part 27 for Normal Category Rotorcraft, Part 29 for Transport Category Rotorcraft, Part 33 for Aircraft Engines, and Part 35 for Propellors. Parts Manufacturer Approvals (PMAs) are the mechanisms for approving other aircraft systems that can be installed on multiple different aircraft, ranging from simple wiring harnesses and brackets to sophisticated avionics systems; if their use requires modifications to the aircraft, then the aircraft may also require an STC. This process certifies that the product meets applicable air worthiness requirements, with the resulting approval then serving as intellectual property that the holder may use to directly produce the aircraft or product, or may license to others.
- **Production Certification:** Under the purview of regulation 14 CFR Part 21, a certified product has to be produced in an organization that has proved to FAA that they can faithfully reproduce an airworthy design. The certification is unique to the manufacturer. Common types of articles (tires, seats, etc.) may be applied that meet the minimum performance standard (MPS) defined under a Technical Standard Order (TSO), but their installation still needs to be shown by the manufacturer to comply with the type certification or approval for the combined system (Parady, 2023).
- **Airworthiness Certification:** Under the purview of regulation 14 CFR Part 21, each aircraft must meet established standards to ensure it is in a safe operating condition. The certification is unique to an aircraft, which is usually indicated by serial numbers. The certification must be maintained over time and can be revoked if something happens to the aircraft. An airworthiness certification is issued to the operator/owner of the aircraft.
- **Operator Certification:** Commercial operations are primarily divided into three tiers: Parts 91, 135, and 121. Part 91 establishes the general operating and flight rules for all operations, and by itself allows only those commercial operations in which an operator does not carry passengers for compensation or hire, such as flight training, aerial surveying crop dusting, and aircraft owners paying services to provide the pilots to transport them in their own aircraft. Part 135 adds additional specifications for operators seeking to provide commuter and on-demand operations and Part 121 adds further specifications for scheduled domestic, international, and large-aircraft charter flights; these higher-level operating certifications require, among other things, additional pilot training, flight attendant training, maintenance, record keeping, scheduling, compliance to financial rules, etc. The certification is unique to the air carrier.
- **Personnel Certification:** Many types of personnel need to be certificated: Part 61 details certification of pilots, flight instructors and ground instructors, Part 63 details certification of other flight crew members (flight engineers and flight navigators), and Part 65 details certification of "airmen other than flight crew members" including air traffic control operators, dispatchers, mechanics, repairment, and parachute riggers. To illustrate what personnel certification covers using pilots as an example, pilots

have to be approved across several dimensions, which includes their training, medical status (14 CFR Part 67), behavioral health, etc. Pilots earn a progression of types of certificates, ratings, and endorsements corresponding to different classes of aircraft and operations. The certification is unique to an individual pilot.

Three general trends exist within this certification structure. First, allowable risk, and the commensurate degree of safety that must be demonstrated, varies depending on the type of aircraft and operation. Relevant certification requirements establish standards relevant to these different aircraft and operations under different "Parts" of the Federal Aviation Regulations (FARs). For example, light-sport aircraft and experimental aircraft are limited to private flights and thus have comparatively fewer, and less stringent, requirements for the operations, personnel, and technologies. In contrast, there are progressively more, and more stringent, requirements for commercial operations of small aircraft, regional airline operations, and the most tightly regulated scheduled air transport operations. This report focuses on the more stringent requirements associated with commercial operations.

Second, FAA certification is structured around current technologies and operations. For example, the pilot is certificated for specific extant classes of aircraft, and the aircraft is mostly certified on the assumption that it will be flown by someone with the skills associated with current pilot certificates. With new technologies, these assumptions may not hold true, such as with an aircraft, otherwise appropriate for certification under the "airplane" class, whose flight control is automated to the point that there is no need for control mechanisms like "yoke and rudder pedals" and the pilot will not need to demonstrate manual flight control skills.

Third, each certificating office within FAA mostly requires demonstration of compliance using methods and measures that have been developed over years or even decades. In some cases, the regulations exactly specify requirements for demonstrating compliance to certification standards, established through a lengthy formal rule making process and development of associated industry standards. In many other cases, the regulations only specify a general requirement, and FAA has developed Advisory Circulars—more detailed guidance on a specific acceptable method for complying with a requirement named in the regulations. While ACs are not mandatory, they offer organizations an accepted method of compliance.[6] As new technologies are developed, Industry Standards Development Organizations develop standards and associated testing guidelines to meet FAA's safety requirements. In many cases, an FAA TSO or AC will, in turn, reference an industry standard and its guidance as a means of compliance with their order.

When seeking certification for technologies and operations fitting within these current structures, organizations generally identify which parts of the FAR apply, and work with the different offices within the FAA AVS to certify separately the technology, its production, the personnel, and their operations. Within each of these separate certification processes, the most unambiguous route is to apply existing demonstrated means of compliance such as provided by ACs and TSOs and referenced industry standards. There are often some gaps in the available guidance, which can be covered by "special conditions" as per 14 CFR Part 11 §11.19 when FAA finds "that the airworthiness regulations for an aircraft, aircraft engine, or propeller design do not contain adequate or appropriate safety standards, because of a novel or unusual design feature."

[6] For some examples, see https://www.faa.gov/regulations_policies/advisory_circulars.

At the time of this report, for example, a special condition has been proposed by Safran Electric & Power and posted in 2024 for public comment for use of an electric motor as the primary source of propulsion for small aircraft certified under Part 23 (e.g., small training aircraft), following an original application for certification in 2020.[7] The proposal cites several difficulties in applying the current regulations, 14 CFR §33, including:

> The existing part 33 airworthiness standards for aircraft engines date back to 1965 [and] are based on fuel-burning reciprocating and turbine engine technology…. Therefore, the existing engine regulations in part 33 address certain chemical, thermal, and mechanically induced failures that are specific to air and fuel combustion systems operating with cyclically loaded, high-speed, high-temperature, and highly stressed components…. In addition, the technology comprising these high-voltage and high-current electronic components introduces potential hazards that do not exist in turbine and reciprocating aircraft engines.

The proposal then provides a substantive list of alternate requirements for certification.

Thus, when proposing transformative changes, organizations face a critical decision: Should they attempt to align with existing certification paths and existing operating procedures with current FAA certification processes? If they do, their process will likely depend on arguing for special conditions, waivers, and exemptions to the existing means of compliance, such as the example in the previous paragraph. They may also find that they need to adjudicate among different certificating offices when, for example, the autonomous aircraft they seek to certify requires different skills and tasks in the pilot certification process. Applicants have reported to the committee cases where they perceived a need to avoid new features for which there is no means of showing compliance, such as control stations supporting flight-critical functions for one or more remotely piloted aircraft, even when these new features may improve safety when viewed in a holistic safety risk management perspective.

Technically, it is allowable for organizations to propose different safety risk management processes to FAA tailored to their new attributes, instead of seeking certification under established means of compliance. However, the process is open-ended and starts with petitions: a petition for an exemption for an individual case, which must include why the request would be in the public interest and proof that the exemption would not adversely affect safety or provide an equivalent level of safety. In a broader case, petitions for rule making may ask for changes to federal aviation regulations and must address a number of societal concerns with cost and benefit, regulatory burden, and effect on the natural and social environments (FAA, 2023).

As an example, a petition submitted in May 2021 asked for exemptions from the regulations that prevent allowing use during on-demand commercial cargo operations of an aircraft reduced from its normal certified status to being certified experimental by adding the capability for nominal flight to be conducted by onboard autoflight and a ground station operator, with an onboard safety pilot ready to take over as necessary; these regulations include §61.113(a), §91.7(a), §91.319(a), §135.25(a), §135.93, §135.115, and §135.143(a) and (b). FAA's response in June 2022 denying the petition demonstrates the careful attention to precedent and the detailed level of scrutiny that is applied, including seeking public comment.[8]

The committee does not have the access to specific data to assess the merits of this particular case, but note it is an exemplar of a key question with implementing transformative

[7] See https://drs.faa.gov/browse/excelExternalWindow/FR-SCPROPOSED-2024-05101-0000000.0001.
[8] See https://drs.faa.gov/browse/excelExternalWindow/FAA0000000000000000000EX19138.0001.

technologies and operations: How to gather the experience and data examining their safety in realistic conditions sufficient to gain approval? The petitioner stated that gathering sufficient data to prove safety only in separate, experimental conditions during nonrevenue flights would be both "financially infeasible" and also "may not adequately represent actual part 135 operations." In response, FAA stated that it "has previously issued multiple denials of exemptions in response to similar requests to operate an experimental aircraft for compensation or hire as presented in the petition" and that "the manufacturer must accomplish each major modification and alteration to the aircraft in accordance with FAA-approved data … to qualify the aircraft for a standard airworthiness certificate" to remove the limits on how and where it operates—and thus requiring all flight data in support of certification be gathered outside commercial operations in the United States. This reflects the fact that some operators are collaborating with the U.S. military for authorization to fly in the NAS (Clouse, 2024), and others first started operations in other countries (Baker, 2017).

SUMMARY: AIR TRAFFIC AND GENERAL OPERATING RULES WITHIN THE NAS

FAA operates the NAS, within which they define the flight rules by which all entities will interact. These flight rules are defined in Subchapter F "Air Traffic and General Operating Rules," which spans Parts 89 through 107 of the 14 CFR. These rules are also translated into the point of view of specific actors through documents such as the Aeronautical Information Manual (AIM) for pilots[9] and the FAA Job Order (JO) 7110.65 Air Traffic Control for air traffic controllers.[10] Appendix A describes, as an exemplar, how the requirements in 14 CFR §91 for instrument landing system approaches are then further codified and detailed in the design of airspace and approach procedures, and in the training and testing material for pilots in the AIM and in JO 7110.65 for air traffic controllers.

The current rules and procedures for the NAS has evolved over decades, constantly being refined any time new safety (or efficiency) concerns have come to light. However, they assume many things about aircraft and pilots. For example, 14 CFR §91 assumes that a pilot is onboard and can visually look out the window. In visual flight rules, this visual capacity is the basis for "see and avoid" of other aircraft, for avoiding terrain and obstacles, and for maneuvering in the traffic pattern around the airport. This visual capacity is required specifically in 14 CFR §91.175 for the transition from performing an approach on instruments to landing the aircraft by visual reference, and must be in place for the pilot and aircraft to be allowed to operate under instrument flight rules.

Throughout this collective set of specifications defining NAS procedures, there are many references to existing certification standards; for example, an instrument flight procedure may require that the aircraft is certified within a designated vehicle "class," which stipulates many aspects of the vehicle's performance, that the ground-based aids to navigation are confirmed to be in operation, and that the pilot has specific ratings within the current system of pilot certification. Likewise, this collective set of specifications provides the performance and safety requirements for many other elements of the NAS: the standards for Certified Professional Controllers, for example, trace to the specifications of NAS procedures, as do the requirements for all the systems supporting the controllers, ground infrastructure at airports, ground navigation aids, etc. (FAA, 2005). Thus, an applicant requesting changes to NAS operations may also be

[9] See https://www.faa.gov/air_traffic/publications/atpubs/aim_html.
[10] See https://www.faa.gov/air_traffic/publications/atpubs/atc_html.

creating requirements for other personnel and other systems throughout the NAS, whose safety also needs to be verified.

In some cases, the same aircraft may operate under different flight rules depending on where or when it flies: for example, a small unmanned aircraft system (UAS) may operate within newer 14 CFR §107 flight rules tailored to UAS operations as long as its radar transponder is OFF and its Automatic Dependent Surveillance-Broadcast (ADS-B) Out equipment is not in transmit mode (and many UAS will not even install these equipment)—but, if the UAS desires to operate beyond the limits of 14 CFR §107 it may instead operate within the general flight rules of 14 CFR §91 if this equipment is turned on, the many additional requirements for the aircraft certification, pilot certification, and so on are met, and the aircraft as operated by its remote pilot demonstrates it can perform all the required flight operations.

Especially if the ATO organization has not been involved from the start, when the technology changes, there can be a substantial lag after a product's certification until updates to operating rules, and all the corresponding changes in airspace design, pilot and controller training, and so on, allow for new, different operations capitalizing on that technology. For example, enhanced flight vision systems (EFVS), which combines imagery from imaging sensors with flight information to show the runway environment during approach and landing, were first certified by FAA in 2001.[11] However, because 14 CFR §91.175 still required pilot visual acquisition of the runway published decision altitudes/heights or minimum descent altitudes, use of EFVS to enable landing in lower visibility conditions—the motivation for implementing the technology—was then only incrementally allowed through a lengthy process. For example, an AC published in 2010 provided a process by which operators could make specific requests to use EFVS, to be considered on a case-by-case basis.[12] Ultimately, following a Notice of Proposed Rule Making in 2013, use of EFVS by pilots was permitted without requiring operators to get special approval under a final rule first published in December 2016 and amended in January 2017.[13]

Highlighting the complexity of operating the vehicle in a new way enabled by a new technology, this EFVS final rule involved amendments in the General Operations and Flight Rules (i.e., the addition of a section, 14 CFR §91.176,[14] allowing an alternative to 14 CFR §91.175) and corresponding changes to 14 CFR §66 adjusting pilot training and recent flight experience, changes to the rules within which aircraft operated by air carriers certificated under 14 CFR §121 and §135 are allowed to initiate and continue an instrument approach, and aircraft certification rules to allow portrayal of vision system video on a heads-up display in 14 CFR §23, §25, §27, and §29 (FAA, 2017). These amendments became effective in March 2018.

This example typifies how merely certifying a new technology does not necessarily translate to allowing for its use in the NAS. The collective set of regulations and guidance defining the general operating and flight rules of the NAS also must be updated if any change to operations is required, particularly if these new operations impact other stakeholders in the system, including other aircraft and air traffic control.

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[11] See https://www.govinfo.gov/content/pkg/FR-2001-06-18/pdf/01-15333.pdf.
[12] See https://www.faa.gov/documentlibrary/media/advisory_circular/AC%2090-106.pdf.
[13] See https://www.federalregister.gov/documents/2016/12/13/2016-28714/revisions-to-operational-requirements-for-the-use-of-enhanced-flight-vision-systems-efvs-and-to.
[14] See https://www.govinfo.gov/content/pkg/CFR-2023-title14-vol2/pdf/CFR-2023-title14-vol2-part91.pdf.

RELATING CURRENT FAA PROCESSES TO FORESEEABLE TRANSFORMATIVE CHANGES TO TECHNOLOGY AND OPERATIONS

An instance where the difficulties of new entrants proposing transformative new technologies and operations led to a significant change in certificating processes has been the rapid wide-spread development of small Unmanned Aerial Systems (sUASs). The first FAA airworthiness certificate for a civil unmanned aerial vehicle was issued in 2005.[15] With the growing number of applications to certify UASs, FAA established the UAS Integration Office in 2012 and, by 2013, they began issuing type certificates for UAS. This immediately enabled case-by-case approval of specific operations such as managing wildfires (FEDWeek, 2013) and arctic surveys (FAA, 2012). FAA issued their first broad operational rules for the use of sUAS in 2016.[16] Since the establishment of the UAS integration office and its commensurate Part 107 regulations, there are more than 781,000 registered sUAS and more than 375,000 licensed sUAS pilots as of February 2024 (FAA, 2024). These Part 107 regulations only directly apply, however, to a limited set of conditions, including operations controlled by a ground pilot via Visual Line of Sight (VLOS), flight under 400 feet Above Ground Level, and vehicles weighing under 55 lbs. Part 107 ends with a description of how to apply for waivers to 10 limits currently in Part 107, and in the past 4 years the FAA UAS Integration Office reports issuing over 600 waivers to Part 107 regulations (FAA, 2024).

However, the UAS Office and Part 107 stand out as a singular development. Other proposed transformative changes to technologies and operations today face similar challenges in navigating the certification process as small UAS did before Part 107 was issued in 2016. Looking forward, FAA is faced with a myriad of new entrants to the airspace, proposing transformative new type of operations using substantially different technologies and architectures, creating a challenge an order of magnitude more complex than previous modernization efforts.

In reviewing the current regulations and processes for safety risk management via certification and operational approval, the committee noted their thoroughness and the decades of experience that they represent. The flip side of these established processes, however, becomes apparent when evaluated for their ability to predict the risk of transformative changes to technology and operations. These processes can be sufficiently specific to current technology and operations that they may be inappropriate for evaluating the safety risk of transformative changes. During the committee's workshops, which brought together FAA personnel from the safety organization with industry proposing transformative changes to technology and operations, the committee was impressed with the openness of FAA officials who engaged in the workshops and briefings about their recognition of the need to accommodate transformative changes. However, these officials also noted that they envision the need for substantial amounts of testing and evaluation, and they do not yet have established metrics and criteria for applicants to plan toward. Likewise, the committee noted that such accommodations are not pervasively reflected through the line personnel in their organizations.

Finding 2-1: Proposals for certifying transformative changes pose a unique challenge when current methods of demonstrating compliance do not sensibly describe their characteristics. Literal adherence to the existing regulations may unnecessarily

[15] See https://www.faa.gov/uas/resources/timeline.
[16] See https://www.faa.gov/sites/faa.gov/files/uas/resources/policy_library/Part_107_Summary.pdf.

complicate and delay any attempt at certification or suggest workarounds that do not necessarily support safety. FAA's role should be viewed as ensuring an acceptable level of risk while at the same time providing a reasonable path for innovation within the broad intent of safety risk management.

Recommendation 2-1: The Federal Aviation Administration Office of Aviation Safety should evaluate current regulations, guidance, and standards to determine if they limit or preclude certification of transformative changes in technologies and commensurate changes in personnel, production, and operating certificates, or appear to disincentivize new features that may enhance safety in different ways than historically assumed. Where such a situation is found, certification processes and standards should be updated to promote effective safety risk management within these new developments, including collaboration with industry where appropriate.

Promoting safety risk management without unduly limiting or delaying the introduction of transformative change in the NAS will require new ways of doing business. It will require a thorough understanding of the operational environment (procedures, equipage, etc.) into which a new aircraft, technology or way of operating will be integrated, as well as analysis of risk in situations in which current distinctions between the functions provided by different personnel and by technology, and where geographically and organizationally they are situated, may no longer apply. Currently, the offices within AVS and ATO that provide safety risk management in certification and in developing new operating rules are largely structured as independent entities. The committee identified numerous cases that cannot be comprehensively addressed independently by current AVS and ATO offices, such as: technologies that may not fit current distinctions of what functions are performed on the aircraft versus on ground-based systems and what functions are performed by humans versus machine; novel flight operations that are different from, yet still need to interact with, current airspace routes and procedures; novel operator practices for safety management; and novel personnel roles not covered by current requirements for personnel certification and training. Thus, addressing transformative changes to technology and operations will require the offices within AVS, and between AVS and ATO, to work together in ways they have not typically done.

Finding 2-2: For most types of operations, the FAA AVS does not currently have mechanisms for comprehensive safety risk management that spans the different organizations certifying technologies, personnel, and operating certificates, and governing the general operating and flight rules of the NAS. Since the regulatory offices are organized around how the NAS operates today, transformative changes can be difficult, if not impossible, to address.

Recommendation 2-2: The Federal Aviation Administration should establish cross-cutting positions, staffed by officials responsible for examining proposed transformative changes that simultaneously seek to manage safety and risk by purposeful, integrated changes to technologies, personnel, and operating certificates, and authorized to identify suitable means of compliance for, and certify, such transformative changes based on their collective mitigation of risk.

PERFORMANCE-BASED STANDARDS

As stated earlier, the committee found that promoting safety risk management without unnecessarily limiting the introduction of transformative change is a challenging problem, which is particularly magnified by certification methods and metrics that focused on historic technology and personnel roles. One specific method to reduce this challenge is to increasingly apply *performance-based standards*. The term "performance-based standard" is defined here as one that stipulates metrics of performance in executing a flight-critical function, regardless of the technology and personnel executing the function and where they are situated. By eschewing prescriptive standards that establish specific technologies or equipment, and instead defining performance outcomes that must be achieved, industry is free, even encouraged, to find innovative solutions that meet a safety performance requirement. For example, a prescriptive standard for an emergency exit would specify something like "Emergency exits must be movable windows, panels, canopies, or external doors that provide a clear and unobstructed opening large enough to admit a 19-by-26-inch ellipse." A performance standard might say, "The aircraft must be designed to facilitate rapid and safe evacuation in conditions likely to occur following an emergency landing." With this shift from prescriptive to performance-based standards, the metrics governing certification are focused on safety, while also being open to innovative methods of meeting the requirement.

The NAS has enjoyed a decades-long exemplary safety record due in part to the layered levels of safety assurance for air traffic operations. If a safety issue makes it through one layer, for example, a demand/capacity imbalance creating a high density of aircraft in one sector of the airspace, air traffic control separation assurance will ensure that aircraft remain a safe distance apart. If that layer fails, onboard collision avoidance systems provide the last line of defense against an accident. However, as illustrated in Figure 2-1, these layers are predicated on a list of assumptions reflecting current technology and operations. These assumptions are then often deeply embedded in regulations and standards; transformative changes upend these assumptions and expose where standards are specified in terms appropriate only for current systems and thus do not allow for innovation.

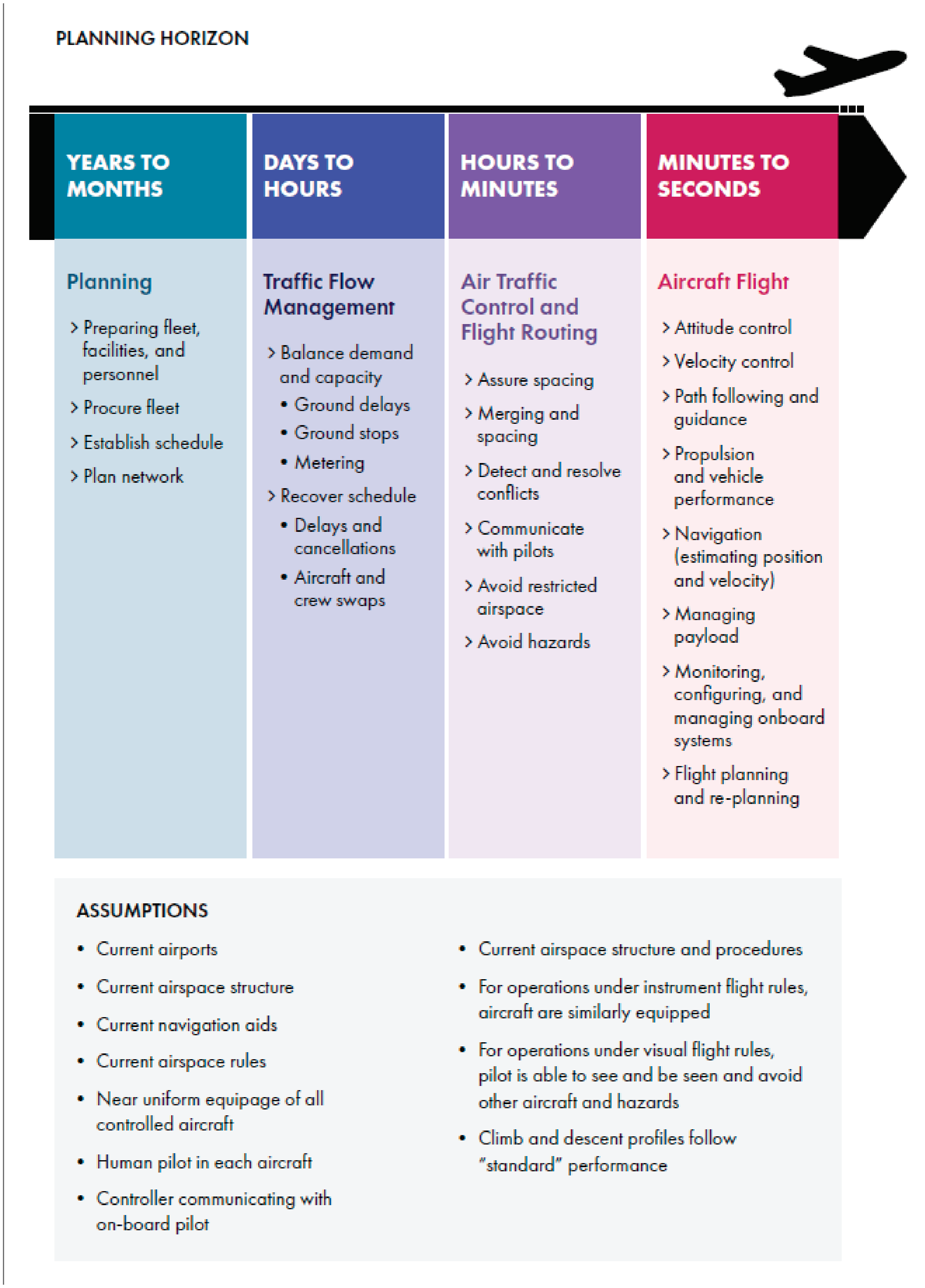

FIGURE 2-1 Layers of defense in current air traffic safety, and the assumptions they are built on.

Not all these assumptions are required for safe flight: what is required is effective execution of the set of critical functions as shown in Box 2-1, spanning the safe flight of each aircraft, aircraft respecting airspace rules and procedures, and aircraft remaining separated from hazards including hazardous weather, terrain, and other aircraft. How an aircraft performs these functions may vary. For example, if the pilot is in the aircraft, there may be no need for a ground control station with a reliable communication link to the aircraft; on the other hand, if the aircraft is remotely piloted, then a ground-based pilot and control station may need to demonstrate they can nominally perform these functions, with the additional requirement that any potential gaps or delays in air/ground communication must be compensated for by onboard capabilities.

BOX 2-1
Aircraft Safety-Critical Functions

Flight

- Attitude control
- Velocity control
- Path following/guidance as appropriate for each phase of flight
- Propulsion and vehicle performance
- Navigation (technically, estimating vehicle position and velocity)
- Managing payload
- Monitoring, configuring, and managing onboard systems (including sensors and controls)
- Flight planning and re-planning

Respecting Airspace Riles and Procedures

- Identifying allowable airspace (potentially defined dynamically)
- Steering to stay in allowable airspace, and performing according to its operating rules
- Stay out of restricted airspace and airspace in which the vehicle cannot meet operating rules

Safe Separation

- Locating the hazards
- Planning and executing maneuvers to avoid them
- Surveillance (technically, locating aircraft within a given airspace)
- Conflict detection and avoidance
- Collision detection and avoidance

Since the 1930s, government and industry have worked together to develop technical standards for critical components of the NAS that can be used as a means of compliance with FAA regulations. These have been upgraded as the system has evolved. However, most standards have been prescriptive. For example, 14 CFR §25.1303 specifies a list of specific instruments that must be installed on large aircraft, and that must be visible from each pilot station; with some transformative technologies, other types of sensors may provide equivalent information and/or there may not be a pilot station onboard the aircraft.

For some functions in some cases, FAA and industry have recently moved away from prescriptive standards to performance-based standards. Standards bodies, such as the RTCA (originally chartered as the Radio Technical Commission for Aeronautics) and the American Society for Testing and Materials (ASTM), for example, have been working to develop standards

(e.g., RTCA Minimum Aviation System Performance Standards [MASPS] and Minimal Operational Performance Standard [MOPS]) that are technology independent. Such standards, when used as a means of compliance with FAA regulations enable multiple means of compliance, thereby supporting innovation. Having said that, much work remains to create the performance-based standards sufficient to cover transformative technologies and operations (e.g., pilot on the ground, pilot controlling more than 1 a/c).

A notable example of the shift from prescriptive to a performance-based standard is for the function of navigation. Early certification standards required aircraft to carry specific systems, such as particular types of navigation radios, which were each certified separately. However, as many different potential systems emerged supporting navigation (e.g., technologies such as Inertial Navigation Systems [INS], long range navigation [LORAN], and global positioning/navigation satellite systems [GPS/GLONASS] supporting area navigation, rather than depending on routes defined by flight to/from ground navigation radios)—and as computing technologies and algorithms for fusing multiple navigation sensors together created integrated systems more accurate than any one component—FAA and the global air traffic system shifted to certify navigation systems based on their ability to precisely locate the aircraft, with requirements on their accuracy, integrity, reliability, and other safety-critical evaluations of potential failure modes. This provided a shared definition of navigation performance that can be applied to both independent components and integrated aircraft systems, and which refer to outside navigation signals as well as, or instead of, depending on onboard systems. Furthermore, navigation systems now self-monitor their navigation performance, and can flag what performance they are achieving at any instant, including in the face of component failures or gaps in ground/satellite reference signals.

This ability to certify an aircraft's navigation performance also then dovetails with defining airspace operating rules. Starting in the 1990s, specific air traffic operations, such as instrument approach procedures, could be extended to allow any aircraft meeting its Required Navigation Performance (RNP) standard to execute procedures that previously were not possible. For example:

> In 1996, Alaska Airlines flew the first RNP procedure in the terrain challenged environment surrounding Juneau, Alaska. Through the establishment of specific requirements for the execution of radius to fix legs [enabling] … curved procedure segments, which followed the Gastineau Channel, [this airspace procedure provided] a safer and predictable path to the airport. (ICAO, 2019)

As integrated navigation systems became more widespread, many other new operations were defined; unlike historic definitions of operations that required specific technologies distributed between air and ground, these new operations are open to any aircraft demonstrating the RNP.

However, many other functions do not have the same definition of required performance to a degree that allows for transformative changes to technology and operations. Examples of proposed transformative changes for which performance-based standards either do not exist or are only in early stages of development or partially apply include:

- Alternate propulsion and energy-storage and power-generation technologies, including those that use electricity to power the aircraft propulsion (whether created by onboard generators or provided by batteries), hybrid systems that use two different

types of propulsion power (e.g., electric for cruise, supplemented by gas for climb), and radically new fuel types such as hydrogen.

- Alternate vehicle configurations involving multiple rotors, in some cases also supplemented by lifting surfaces that themselves may be tilted or freely rotating.
- Airspace and air traffic functions performed by different technologies than those assumed in the operating rules, such as those assuming the vision of an onboard human pilot as the primary mechanism for detecting other aircraft and/or for detecting the runway during approach and landing.
- The shift of any aspect of the "Aircraft Functions" from being performed onboard the aircraft to being performed by some combination on onboard autonomous technologies and a pilot located on-the ground and beyond visual line of sight, or by a third-party service provider.[17]

These efforts show the challenge, and the potential, of expanding performance-based standards for certification and operational approval, but they are also notable for being limited to isolated cases. A more pervasive and comprehensive development of performance-based standards could enable a much wider range of innovations in technology and operations.

To illustrate how performance-based standards may be developed by FAA alone or by industry-wide committees, RTCA minimum performance standards begin with an Operational Services and Environment Definition (OSED). As new entrants with unique concepts of operation, such as Unmanned Aircraft Systems (UASs) emerged, RTCA published an OSED (2022) to guide its development of Detect and Avoid (DAA) standards for these remotely piloted systems. The purpose of this OSED was to provide a basis for assessing and establishing operational, safety, performance, and interoperability requirements for DAA systems.

As even more innovative technologies and operational concepts are developed, it will become necessary to develop more performance standards accommodating how they perform the critical functions noted in Box 2-1 in innovative ways. These will require OSED-like documents to identify all assumptions that could affect safety for both the applicant and all those potentially impacted by them in the airspace. For example, to certify operations in which one ground pilot could be remotely piloting multiple aircraft, all such characteristics of the operation and the airspace in which it intends to operate, and the airports or landing sites from which it intends to takeoff or land, must be spelled out, and safety requirements must be allocated to each component of the operation. In this example, standards will need to capture all aspects of these operations in a manner that allows for a range distribution of technology-specific implementations of what people and systems collectively perform the function, including a range of possible variants between what occurs onboard the aircraft and what is executed on the ground, and a range of autonomous functions between minimal pilot support to fully autonomous functions. Only this level of detail will allow for the necessary detailed examination of the skills the personnel will need and confirmation these personnel have appropriate workload,

[17] One industry participant in the committee's workshops perceived that, at this time, there is no standard for certifying the ground control station for remotely operating an autonomous midsize cargo aircraft. If such a standard is based on component technologies, it would be difficult to establish without limiting it to particular specifications of which functions are performed remotely by the pilot or ground-based technology and which are performed automatically onboard the aircraft.

information, and control authority. and a commensurate detailed specification of the behaviors required from technologies both onboard the aircraft and on the ground.

Finding 2-3: Current standards for certification and operational approval for many functions necessary for safe flight prescribe technologies, roles, and skills for personnel, and operating rules that assume historic concepts of operations and architectures. These assumptions do not fit with, and can conflict with, proposed transformative changes to aviation technology and operations. Instead, performance-based standards can direct assessments of how well a proposed technology or operation meets safety standards and do so in a manner directly supporting certification and operational approval.

Recommendation 2-3: The Federal Aviation Administration Office of Aviation Safety should lead the definition of performance-based standards for flight-critical functions that allow for different equipage, different methods of performing the functions, and a different distribution of who or what is performing the functions' constituent activities, including changes in distribution of activity between human or machine, on the aircraft or on the ground, by the operator (e.g., airline), air traffic or a third party. These performance-based standards should be developed to the point that they can serve as a basis for certification and for approving new operations within the National Airspace System.

CHANGES TO GENERAL OPERATING AND FLIGHT RULES

The committee recognized that a central feature of many transformative changes is the applicants' need for changes to general operating and flight rules governing how aircraft operate in the NAS. For example, some proposed aircraft for very short air taxi flights or last-mile airborne cargo delivery may not operate out of current airports and may never reach the altitudes at which most air traffic control functions are invoked. Others, such as supersonic or high-altitude long-endurance aircraft, may cruise at high altitudes but require very different speeds and climb/descent rates to get there.

Where they cannot meet the specifications defined in 14 CFR Part 93 or Part 107, they will require exceptions to current general operating and flight rules or generation of new operating rules. Unlike certification of individual systems or entities, these operating rules must also address concerns of all stakeholders impacted by the new operations. Short, low air taxi and cargo delivery flights, for example, may need low altitudes and routes of flight over urban areas that interact with low-level medevac and law enforcement helicopter operations and that must address community concerns with noise, privacy, and safety of sensitive locations on the ground.

These operating and flight rules can be central to a holistic assurance of safety in that they can help define the performance-based standards for what the technology and the personnel need to do. However, as noted earlier in this chapter, there is a long history of having technologies certified but then a lengthy delay until their commensurate new operations are approved.

Unfortunately, while engineering methods exist for failure-assessment of technology in support of technology certification, there is no equivalent systematic, rigorous, broadly documented method for assessing novel operating and flight rules. Thus, while the certification path has (to varying degrees) some definition that an applicant can use to predict timeline, test

and evaluation requirements, and so on, there is no clear path to operational approval. As noted earlier and characterized in an example in Appendix A, operational approval can require many changes throughout the NAS.

At this time, these challenges are being addressed by examining proposed changes each on a case-by-case basis. For example, a recent Aviation Rulemaking Committee (ARC) examining Beyond Visual Line of Sight (BVLOS) UAS operations,[18] and an RTCA forum on Digital Flight Rules, each advocated for specific changes in operating rules.[19] These exemplars illustrate the careful and detailed attention required for changes to operating rules, and the significant number of stakeholders and types of analyses that are necessary to evaluate changes to operating rules. Of note, in the absence of an established framework and methods for analyzing operating rules, these studies each approached their task in different ways, and needed to develop metrics and methods from first principles.

Furthermore, different operators cannot create competing operating rules. For example, if several advanced air mobility (AAM) applicants and commercial drone package delivery services each propose their own preferred operating rules independently, they can't all be approved simultaneously if they might in any way conflict or obstruct each other (e.g., differing assumptions of how to define low-level air routes or safe operating zones or altitudes). Likewise, unless there is some mechanism for ensuring new types of operations are decoupled (commonly described as "segregated") from current operations, they must be made interoperable and not adversely impact others in the airspace.

Finding 2-4: Radical transformations to general operating and flight rules are being proposed, or will be necessary, to safely operate proposed vehicles. However, there are no systematic, rigorous, broadly documented methods for identifying, categorizing, and analyzing the risks that may emerge with novel operating and flight rules, especially where the changes are sufficiently transformative that they cannot be predicted via extrapolations from the present day.

Recommendation 2-4: Congress should ensure that fundamental and generalizable research is chartered to establish a systematic and repeatable framework for analyzing and designing civil aviation general operating and flight rules that enable novel technologies and operations to share the airspace with current operations. This requires fundamental and generalizable research beyond the Federal Aviation Administration's current research expertise and portfolio, and may need the support of other agencies conducting fundamental research into operational system-wide safety. These methods must calculate the appropriate performance requirements for all the functions noted earlier, be able to identify and characterize safety concerns created or mitigated by the operating and flight rules, and be detailed enough to articulate the specific activities, and required information needs and control authority, of all actors and stakeholders and how these activities combine to create safe operations.

[18] See https://www.faa.gov/regulations_policies/rulemaking/committees/documents/index.cfm/document/information/documentID/5424.

[19] See https://www.rtca.org/news/digital-flight-report.

Finding 2-5: Different aircraft operators cannot use conflicting general operating and flight rules in the same airspace, highlighting that these flight rules cannot be developed independently by individual applicants, but must have some guiding structure and constraints that is fair to all in terms of access to the airspace and safety for all in the airspace while minimizing undue constraints on innovation.

Recommendation 2-5: The Federal Aviation Administration (FAA) and the aviation industry should develop a process for defining the general operating and flight rules that enable new, innovative operations to coexist in the airspace with other innovative operations as well as legacy operations. FAA should launch a single-purpose group (e.g., task force, aviation rule making committee) including representatives of all relevant stakeholders from legacy and new operations for the purpose of identifying the fundamental structure of and constraints on operating and flight rules for broad classes of current and proposed new operators in the National Airspace System. This should include consensus-based recommendations for development of technical standards that characterize all relevant aspects of the proposed operations relevant to assessing their safety and that identify the essential constraints on and performance measures of new operating rules needed to address potential risks emerging from changes in the operations.

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3
Integrated Safety Management Across the Lifecycle and Across Organizations

Even after the most rigorous safety risk management process, safety concerns will continue to emerge as a system is implemented and operated, for many reasons. Some concerns may only become apparent in real operations. Other concerns may be very subtle and require more experience and data to identify and characterize. Furthermore, new concerns may arise over years or decades as a technology or operation that had been "safe" becomes stressed by changes in the operating environment and other external factors. Last but not least is the obvious reason that no system will ever be perfect.

Thus, the second component of safety management, *safety assurance*, is critical. Often discussions of safety assurance focus primarily on the data that is collected, and the analysis that is conducted—and this chapter discusses the challenges and opportunities in data analytics with transformative changes in technology and operation. Furthermore, safety assurance is only truly effective not only if it monitors safety performance but also if its insights are fed back to improve safety risk management, and it's used to manage change within an organization (detailed in the next chapter).

REVIEW OF CURRENT PROCESSES FOR SAFETY ASSURANCE

Safety assurance at some level is expected in all types of aviation operations, and at all stages. Looking at each aircraft, monitoring, and quality checks are important throughout production and manufacture, with ongoing safety assurance and management expected as part of the production certificate. Once manufactured, aircraft operators have routine inspections and monitoring for safety conditions arising within the aircraft, with detailed maintenance logbooks for each aircraft. Often, operators, original equipment manufacturers (OEMs), and maintenance, repair, and overhaul (MRO) operations collaborate to create mechanisms for detailed health management that allows them to identify when something mechanical may be degrading and to purposefully anticipate an efficient schedule for repair or replacement before it becomes a safety concern. The rare instances of a major malfunction in flight are typically viewed as failures in this vehicle health management cycle, triggering reviews of the design of the failed component, and its manufacturing and maintenance, to not only identify cause of the failure but also adjust the schedule of inspections and repair, and confirm that the appropriate assessments are being made to capture failure modes.

Likewise, within flight operations all parties are expected to monitor for, and investigate and address, safety concerns as they are detected. With the more stringent requirements operating certificates associated with commercial operations, especially Part 121 operations, operators are required in 14 CFR §119 to have a safety management system (SMS) as detailed in

14 CFR §5. This SMS must encompass all the aspects of safety management detailed throughout this report. Some of these aspects establish important aspects of the operation but then do not need day-to-day activities: the required aspects of safety policy and safety promotion establish organizational structures, policies, and plans; and, for an aircraft operator whose aircraft and operations have already been evaluated through a rigorous safety risk management process during FAA certification and operational approval, the safety risk management aspect of their SMS largely serves as an extension of the earlier hazard analyses, providing a reference point and directing where safety assurance should be gathering and analyzing data.

Thus, ongoing safety assurance is the most active component of the SMS. It typically involves and is visible to line personnel and includes substantial data collection and analysis. The required elements of this safety assurance include the stipulation in 14 CFR §5.71 of what processes and systems "safety performance monitoring and measurement" must monitor for, including establishing a confidential and nonpunitive employee reporting system. 14 CFR §5.73 then requires assessments of safety performance including ensuring compliance with the operator's own safety risk controls defined in their safety risk management process, identifying new hazards and changes in the operational environment that may introduce new hazards, and evaluating the performance of the SMS. 14 CFR §5.73 concludes the regulatory definition of safety assurance with a requirement for continuous improvement: "The certificate holder must establish and implement processes to correct safety performance deficiencies identified in the assessments conducted under 14 CFR §5.73."

Several types of data are commonly applied to the extensive safety assurance programs typical of current air transport:

1. Digital Data. Much of the data are logged by onboard digital flight data recorders, whose minimum specifications are given in 14 CFR §121.344. These specifications focus on capturing through time the variables defining the flight dynamics of the aircraft (e.g., airspeed, acceleration, pitch and roll), the control inputs put into the aircraft by the pilot or autoflight system and control surface positions, key markers of onboard systems (e.g., hydraulic pressure, thrust/power, fuel status, cabin pressure), and flight conditions (e.g., wind, outside air temperature). Some measures of the pilots' actions are also included (e.g., when they transmit on the radio, and some of the autopilot and display settings). Likewise, where systems are installed that detect hazards, they may record the warnings that they trigger, or at least indicate that a master warning was given to the pilots. Other data sources may also be integrated, such as flight tracking and meteorology data openly available on the Internet.
2. Voluntary Safety Reports. As noted earlier, an organization must establish voluntary nonpunitive safety reporting systems as a required element of an SMS.
3. Observations and Assessments. Air transport is a leader in creating methods of observing and assessing a range of aspects of their operation. In the first report, for example, the committee noted the broad use of Line Operations Safety Audits (LOSA) in which observers ride in the "jump seat" and observe flight crew in normal flights to determine leading indicators of both what might be going wrong, and of what it takes for things to "go right."

These types of data can be analyzed in several ways. Of course, any reports or flags of major safety issues can combine multiple types of data into an intensive, focused investigation.

For ongoing analysis and monitoring, particularly for the digital data, current methods in Flight Data Monitoring (FDM) or Flight Operations Quality Assurance (FOQA) tend to focus on establishing some upper and lower bounds on recorded parameters, and then identifying any "exceedances" of these criteria. For example, examining some of the phenomena that are currently viewed as important to monitor, an international consortium has examined the flight parameters defining stabilized approaches, flagging criteria such as deviation of airspeed relative to desired approach speed, and deviation from localizer and glideslope, that should be flagged.[20]

Safety management requires that each organization analyze their data internally and frequently, with a particular call to be alert and responsive to any concerns as they are identified. The air transport industry has further found benefits in collaborating, as highlighted by the activities of the Commercial Aviation Safety Team (CAST) and the Aviation Safety Information Analysis and Sharing (ASIAS) initiative, whose members and contributors span most of the U.S. aviation industry, in partnership with FAA AVS and ATO and including representatives from labor through pilot and air traffic controller associations. By pooling their data, their analysis of it, and their decisions on the appropriate changes and improvements to implement, such collaborations allow not only sharing of insight but also highlight where concerns are system-wide and impact many.

Another system-wide assessment comes from the Aviation Safety Reporting System (ASRS). Run by the National Aeronautics and Space Administration (NASA) with funding from FAA, the ASRS is the model and progenitor of many other VSRPs, including those created by individual organizations as part of their SMS. ASRS has been in place for over 45 years and in 2023 received more than 106,000 reports from pilots, air traffic controllers, cabin crew, dispatchers, maintenance technicians, UAS operators, and others.[21] Uniquely, de-identified ASRS reports are made public in a searchable database that is widely used for training and education, safety analyses, and research. However, because the reports are de-identified before public release, it can be difficult to then examine specific incidents in detail.

While a great volume of data is collected across the system, it can be hard to integrate and share for two reasons. First, different data sets are often collected using constructs that do not easily mesh. For example, both digital flight data recorder data and air traffic control voice radio logs exist, but the process of relating what was said by and to the flight crew to the other events occurring through the flight, particularly as the aircraft transitions between air traffic sectors using different radio frequencies, requires such effort and time that it is limited to special situations. More pragmatically, different flight data recorders may use different formats or units—different operators' VSRP may ask different questions—and different observation programs, such as LOSA, may be targeted to, and document, different safety concerns. Thus, there can be significant cost and time required to integrate data, and the choice of what to integrate must be purposeful.

Second, significant policy concerns can limit the open publication of raw data. Information collected by air carriers can include elements considered proprietary to themselves and/or to the manufacturers of equipment that is being sensed and recorded. Requests for sharing measures of human performance, behavior or physiology, including audio and video recordings, raise significant concerns with individual privacy and impact labor relations. Taken out of context, raw data is easily misrepresented or misinterpreted. Thus, an important consideration in

[20] See https://www.iata.org/contentassets/b6eb2adc248c484192101edd1ed36015/unstable-approaches-2016-2nd-edition.pdf.

[21] See https://asrs.arc.nasa.gov/docs/ASRS_ProgramBriefing.pdf, retrieved May 30, 2024.

the analysis of emerging trends in aviation is understanding who can have access to data, and understanding the processes by which data can be shared with others or, ultimately, be made publicly available.

One major contribution of ASIAS is its function of gathering major data sources and controlling their dissemination to provide public access where possible, and to provide strong data protections otherwise. The development of this data sharing collaborative is now more than 15 years in the making, reflecting the long-time frame required to develop the trust, policies, and formats for the most sensitive data. Their strong data protections, including a clear understanding of who will have access to the data, the analyses it will be used for, and the type of results and outputs of the analyses (and their dissemination) are generally considered important factors in decisions by air carriers, labor associations, and other parties to voluntarily contribute data that they otherwise might not share—indeed, that they otherwise might choose to not even collect.

OPPORTUNITIES AND CHALLENGES FOR DATA COLLECTION SUPPORTING SAFETY ASSURANCE WITH TRANSFORMATIVE CHANGES TO TECHNOLOGY AND OPERATIONS

Stepping back to make a holistic assessment of the types of data that can be collected—and that are required for safety assurance of novel technologies and operations—the committee noted both challenges and opportunities. First, many new technologies afford opportunities to record more data in several ways. For example, they may be highly instrumented to dynamically control specific components or to improve pilot situation awareness; a highly automated UAS, for example, may have many more sensors on it than a traditional aircraft; modern avionics are capable of recording many data streams and calculating a more comprehensive picture of the flight conditions. Furthermore, once certified, it is expensive to modify flight-critical software to record its internal data streams and logic. Thus, the decisions regarding which data should be recorded by increasingly data-intensive flight systems need to be made early in design.

Second, a challenge and opportunity with many transformative technologies is to accommodate the different roles—and even locations—of human operators, and to capture measures of critical interactions between human operators and machine components. The current standard captures digital flight data focused on simple measures of human-machine interaction. This digital data is supplemented by VSRP reports by onboard pilots who can explain their concern. However, the current framework of VSRPs may not capture many new forms of human-machine interaction. For example, within the traditional data set, while the autoflight system modes are captured, the pilot's button presses commanding the modes may not be, leaving ambiguous whether important mode transitions were commanded implicitly by the autoflight system or explicitly by the pilot, and not capturing interactions such as a pilot being confused when a button press does not trigger a desired mode change. At the same time, the pilot may be distanced from some of the direct control functions, and not positioned to identify safety concerns in the same way. Thus, this point in time is an opportunity to examine what data needs to be recorded to analyze the new types of interaction.

Third, as Leveson notes, "any attempt to determine whether software is safe or not without including the context in which it is to be used will not work" (Leveson, 2023, p. 132). Unlike physical systems, that may mechanically break so that they fail in intended operations (and may continue to function in unusual conditions), software does not mechanically break. Absent some malfunction or abnormality, software instead continues doing exactly what it is

programmed to do. This creates two types of failure modes that are difficult to identify with current safety assurance data sets, namely, (a) when placed out of intended context, the software's behavior may have undesired or unsafe outcomes; and (b) the specification of the software's behavior can be wrong or incomplete.

Fourth, an opportunity in safety assurance can be created with a shift to performance-based standards, as recommended in the previous chapter. These standards would establish metrics suitable not only for safety risk management but then also for safety assurance: metrics of system performance can be directly measured, calculated and recorded, even in real time during a flight. This particularly helps with assuring functions performed by multiple interacting components (where each could appear to be acting according to its own specifications even as the overall function degrades), and with providing high-level specifications of what the software behind the function should be performing toward.

Finally, a challenge and an opportunity in safety assurance exists when examining transformative changes to technology and operations. The challenge comes from this report's definition of "transformative"—that is, innovations for which current methods of predicting safety do not extrapolate or predict safety well. Safety assurance using traditional data and criteria may miss critical concerns with transformative changes; for example, the flight data recorder data set contains measures of fuel and engine settings that do not apply to electric engines, and the criteria for stabilized approaches assume different profiles for airplanes and helicopters, a distinction that can be blurred with novel "powered lift" category aircraft. As noted in the previous chapter, safety risk analysis is grappling with the challenge of identifying appropriate metrics of safety during certification and operational approval.

The opportunity exists for safety assurance to learn from, and apply, the metrics and criteria employed in safety risk analysis of transformative technologies and operations. Continuing with the same examples given in Chapter 2, FAA has recently published special conditions for certifying Safran's proposed electric motor and power system under 14 CFR §33[22] and proposed airworthiness criteria for one powered-life design, the AgustaWestland AW609 tilt-rotor, designated a "special class" aircraft under 14 CFR §21.17(b).[23] Such special conditions provide detailed criteria, and require the applicant to develop sensors, measures and methods for certification. These developments that can then be left in the design to support subsequent safety assurance. For example, the AW609 proposed airworthiness criteria includes several criteria governing its transformative aspect—the transition from vertical flight with the rotors "up" to forward flight using its wing and the rotors "forward," such as §TR.191(d) "*Control margin*. To allow for disturbances and for maneuvering, the margin of control power remaining at any stage in the transition shall be demonstrated to be adequate." The measures defined for special conditions during certification can also be captured during implementation to support on-going safety assurance.

> Finding 3-1: Proposed transformative changes in technology and operations provide both challenges and opportunities to rethink the appropriate data to collect to support safety assurance. Given that many new technologies can record a wide range of new measures, the opportunity exists to systematically determine what potential data streams best monitor potential safety concerns emerging with innovations. This should particularly

[22] See https://drs.faa.gov/browse/excelExternalWindow/FR-SCPROPOSED-2024-05101-0000000.0001.

[23] See https://www.federalregister.gov/documents/2023/06/09/2023-12310/airworthiness-criteria-special-class-airworthiness-criteria-for-the-agustawestland-philadelphia.

consider the unique safety concerns with changing roles of human and machine, and with the unique concerns with monitoring software-intensive functions. This should also capitalize on criteria used in certification and approval of transformative changes, including monitoring of criteria applied earlier in certification and other safety risk management processes based on performance-based standards and on special criteria and conditions.

Finding 3-2: Voluntary Safety Reporting Programs (VSRP) are a vital data source in safety assurance, given the ability of personnel throughout the NAS to detect and describe anomalies. Changing roles between human and machines, particularly with increasingly automated functions and remotely piloted aircraft, may impact human observability of safety concerns. In such cases, the personnel expected to provide VSRP reports, and the questions they are asked within the report, may need to change. Likewise, further digital data may be required to make up for gaps in, and to make sense of, VSRP reports.

Recommendation 3-1: The Federal Aviation Administration Office of Aviation Safety should determine the process and criteria by which an applicant can demonstrate that their proposed data set is appropriate for safety assurance when implementing transformative changes in technology and operation. This determination should be sufficiently proactive to identify where new sensors and recording mechanisms need to be built into systems during their design and certification to then enable safety assurance during their operation. These data sets can leverage the criteria used in safety risk management (including certification and operational approval) to demonstrate safety of their new attributes through performance-based standards and through the special conditions and criteria.

OPPORTUNITIES AND CHALLENGES FOR DATA ANALYSIS METHODS SUPPORTING SAFETY ASSURANCE WITH TRANSFORMATIVE CHANGES TO TECHNOLOGY AND OPERATIONS

As noted earlier in this chapter, and in the committee's previous report, current methods for data analysis focus largely on flagging "exceedances" (e.g., airspeed higher or lower than some criteria) and for lagging indicators such as incident reports. This report notes that the definition of "emerging" includes both known constructs that are increasing in magnitude or frequency, and unknown constructs that may appear later, even years into an operation. Given the many forms of data analysis enabled by fields such as data mining and machine learning, more and better is possible in both characterizing and predicting known (or hypothesized) safety concerns, and monitoring for the unknown.

A major distinction is between data analysis for phenomena that are completely unknown, and for those phenomena that are known (or hypothesized). Current methods for measuring exceedances typify analysis for phenomena known so well that a high or low value in a specific variable is mapped to a safety concern. In this case, the exceedances are counted in order to assess whether they are growing in magnitude overall, or particularly occurring in specific situations. For example, exceedances such as high or low airspeed may be considered a marker of an unstabilized approach for current operations, and they can be monitored to see if

they are occurring at a particular airport or with a particular aircraft type.[24] The committee notes that this type of detailed monitoring for those conditions that are well characterized and appropriate to the technology and operation is a vital first step in safety assurance.

The concept of monitoring for exceedances can be extended to also monitor for violation of critical metrics and assumptions relied on during design and safety risk management. Flight-critical software can assist with reporting whenever its logic detects hitting any key metric or assumption built into its algorithms. Likewise, onboard systems or offline analysis can track metrics relative to required performance as developed for the first time as part of special conditions, special criteria, or exemptions for certification and operational approval.

Further data analysis methods can bring more insight to safety assurance. As a next step, methods such as association rule-learning and dependency modeling may look for relationships between variables to enable more multidimensional evaluation of a safety concern. Analysis of the time history of many variables may find time sequences and patterns that precede exceedances. Once characterized, these patterns and sequences often provide a "signature" that a future undesired event may be developing, which can then be monitored for. For example, these methods may more fully characterize unstable approaches as patterns across speed, descent angle, power setting and control activity rather just flagging flights with an exceedance in only one variable, such as a low speed. This will provide more insight into exceedances in post-hoc analysis; such insights can conceivably also be used in real time to flag to the pilot or others that a potential situation may be developing, where it may support an immediate response.

Progressively more sophisticated analyses may seek to characterize phenomena that are only understood—or hypothesized—in general terms, such as "pilot mode confusion," for which no screening criteria currently exist. For example, in 2008, NASA Aeronautics research demonstrated how algorithms could quickly analyze the time history of pilot button presses across thousands of flights (Budalakoti, 2008). Their "sequenceMiner" algorithm learned what typifies "normal" sequences of button presses, and then with that knowledge identified "abnormal" cases; for example, the algorithm flagged a hither-to unidentified case of a pilot pressing the autopilot switch numerous times at three points: 16 minutes, 4 minutes, and then 1 minute before landing. Once flagged, a subject-matter expert analyzed the case and confirmed it as an instance of pilot mode confusion.

Ultimately, current data analysis capabilities created in other disciplines and applied in other industries can also support the ultimate step of monitoring for effects that are sufficiently unknown that an operator does not know to monitor for them. Methods such as "clustering" large multivariate data sets can identify the patterns of data typifying "normal" operation—and then flagging "abnormal" situations. These results supplement rather than replace the role of the human analyst in safety assurance, enabling them to focus on the statistically unusual cases.

Unfortunately, little research has been conducted and documented in the public domain on how such methods of data analysis can be applied to the full range of analysis that aviation safety assurance requires. The committee knows of no recent research by federal agencies. Likewise, the sensitive nature of aviation data, and the absence of publicly available data sets, has limited open research into the extension of general data analysis methods to aviation.

Finding 3-3: Extensive data analysis methods have been established in other domains and industries suitable for expanding the capabilities of aviation safety assurance. These

[24] Committee discussions included experiences in which exceedances could be traced back to specific flight instructors.

methods particularly span the needs of transformative changes to technologies and operations, where simple definitions of exceedances cannot span the open questions in possible safety concerns that need to be monitored for; instead, transformative changes require a range of methods, from those suitable for monitoring for, characterizing, and predicting potential concerns to detecting the unknown.

Recommendation 3-2: The Federal Aviation Administration Office of Aviation Safety should determine the process and criteria by which an applicant can demonstrate that their proposed data analysis methods are appropriate for safety assurance when implementing transformative changes in technology and operation, and that they are appropriate for the data set being collected. This determination should specifically support both (1) characterizing phenomena that are only hypothesized or poorly understood as a result of transformative changes; and (2) monitoring for situations and conditions that are unknown and statistically abnormal, and thus should be flagged for further evaluation.

OPPORTUNITIES AND CHALLENGES FOR CHANGE MANAGEMENT AND CONTINUOUS IMPROVEMENT IN SAFETY ASSURANCE WITH TRANSFORMATIVE CHANGES TO TECHNOLOGY AND OPERATIONS

As defined in Chapter 1, safety assurance only starts with collecting and analyzing data—the insights from the analysis must be applied to manage change and continuous improving the technologies and their operation—and improving the SMS itself. This is noted in FAA's guidance on SMS:

> SMS requires the organization itself to examine its operations and the decisions around those operations. SMS allows an organization to adapt to change, increasing complexity, and limited resources. SMS will also promote the continuous improvement of safety through specific methods to predict hazards from employee reports and data collection. Organizations will then use this information to analyze, assess, and control risk. Part of the process will also include the monitoring of controls and of the system itself for effectiveness. (FAA, n.d.)

This full vision of SMS is also integral to the recognition that AVS cannot personally oversee every aspect of a design and operation: instead, they depend on the organization having the internal systems and processes in place to manage safety. Unfortunately, members of the committee noted instances, both in their own experience and noted in other recent public discussions of safety breakdowns,[25] where organizations implemented SMS in strict accordance with FAA criteria, including the required data collection and analysis aspects, without visible evidence that the SMS was then used to drive change.

Several markers can be captured of an organization's use of SMS to affect change. For example, best practices in flight crew procedures and checklists include welcoming feedback by all for "the assurance that the cold light of the real world is the final test of the goodness of any individual procedure or policy."[26] While there is no single target number for the number of pilot

[25] Final Report: Expert Panel Review of Section 103 Organization Designation Authorizations (ODA) for Transport Airplanes, 2024.

[26] See https://ntrs.nasa.gov/api/citations/19940029437/downloads/19940029437.pdf.

reports, and the number of changes made in response, tracking these numbers can flag situations that are clearly off: too few reports suggests a problem in the reporting process; too few changes in response suggests a problem in the organizational response; too many reports suggest an abnormal breakdown that line personnel find concerning; and too many changes may reflect a process of churn within the organization's policies and procedures that can itself be de-stabilizing.

This committee is not alone in its concerns with ensuring that implementation of SMS actually leads to effective safety management. Similar concerns were noted in the recent Expert Panel Review Report for Organizational Designation Authorizations (ODA) for Transport Airplanes. One of their recommendations to FAA was to "partner with industry to define clear measures of success for SMS implementation for … organizations and jointly review those measures of success on a regular basis."[27] While this expert panel was focused on design and manufacturing, this recommendation is also appropriate to all aviation organizations contributing to safe operations—that each safety assurance process needs to include assessment of itself and of its organization's broader safety management.

The following chapter continues this discussion of managing change within the organization through the lens of Safety Culture, and provides findings on the role of SMS in helping measure and guide the maturity of safety culture.

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[27] See https://www.faa.gov/newsroom/Sec103_ExpertPanelReview_Report_Final.pdf.

4
Safety Culture

In theory, an organization's safety culture will drive how well it can actively manage safety, and the practices required for safety management can serve as a learning process to mature that safety culture. In this chapter we focus on two critical aspects of safety management: organizational processes and culture. First, as part of its overall charge to "assess whether … available sources of information are being analyzed in ways that can help identify emerging safety risks" the committee is also tasked to "draw on the results of FAA's [Federal Aviation Administration's] annual internal safety culture assessments and also advise the agency on data and approaches for assessing safety culture to assure that FAA is identifying emerging risks to commercial aviation."

Thus, the first section of this chapter provides an update on the annual safety culture assessment by FAA's Office of Aviation Safety (AVS).[28] Because other safety critical industries, particularly nuclear power, have begun to explore the safety culture of regulators and its effect on operators, the second section introduces this relatively new concept and discusses whether this construct should be adopted by AVS. Consistent with the overall emphasis of this report on new entrants, the third section describes strategies FAA could use to ensure that industry—especially "new entrants"—develops mature safety cultures by monitoring, evaluating, and responding to the safety management practices industry adopts.

STATUS OF AVS SAFETY CULTURE ASSESSMENT

Safety Culture and Its Assessment

From Culture to Safety Culture

Organizational culture is widely acknowledged by experts in the field as difficult to define and challenging to measure. Many experts rely on theory developed by Schein (2010), who proposes that organizational culture has three levels:

- **Artifacts**—visible manifestations of culture (logos, history, headquarter design/layout, dress code, styles of communication, how people are rewarded or punished, how to get ahead, how conflicts are managed);
- **Espoused beliefs and values**—mission statements, stated core principles, written policies, public statements, etc.; and

[28] AVS is responsible for the certification, production approval, and continued airworthiness of aircraft; certification of pilots, mechanics, others in safety-related positions, commercial airlines, operational and maintenance operations, civil flight operations, and for safety regulations. See https://www.faa.gov/about/office_org/headquarters_offices/avs.

- **Shared assumptions**—collective understanding of how an organization faces and overcomes significant challenges, including adapting to external events and internally integrating these adaptations.

For Schein, shared assumptions are typically deeply rooted and taken for granted, so much so that they are not readily articulated by participants or leaders. Shared assumptions within organizations include collective understanding about past behavior and values, including how important decisions were reached in the past, and their consequences, in response to significant challenges for the organization as a whole or within operating divisions.

Weick and Sutcliffe (2015) summarize and slightly modify Schein's formulation as follows:

> In Schein's view, culture is defined by six formal properties: (1) shared basic assumptions that are (2) invented, discovered, or developed by a group as it (3) learns to cope with its problems of external adaptation and internal integration in ways that (4) have worked well enough to be considered valid and, therefore, (5) can be taught to new members of the group as the (6) correct way to perceive, think, and feel in relation to those problems. The one addition we would make to point 6 is that *culture is as much about practices and actions as it is about mindsets*. [Emphasis added.] When we talk about culture, therefore, we are talking about
>
> - Assumptions that preserve lessons learned from dealing with the outside and the inside;
> - Values derived from these assumptions that prescribe how the organization should act;
> - Practices or ways of doing business;
> - Artifacts or visible markers that embody and give substance to the espoused values.
>
> Artifacts are the easiest to change, assumptions the hardest.
>
> What Schein has spelled out in careful detail, people often summarize more compactly, "how we do things around here." For our purposes, we amend that slightly and argue that culture is also "what we expect around here."

There are several overlapping conceptualizations of the safety culture of an organization. At its core, it can be thought of as the priority that an organization assigns to safety as represented by its assumptions, values, practices, and artifacts. In the private sector, this priority often reflects the priority given to safety against other goals since companies must be profitable to survive and the only way for an airline to be 100% safe is to not operate. That said, companies have demonstrated the ability to operate at very high levels of safety while also being profitable. For example, under the leadership of Paul O'Neill over the 1989–2000 time period, Alcoa achieved a remarkable record of both safety and profitability. "O'Neill has been quoted as saying 'Safety should never be a priority. It should be a prerequisite'" (Leveson, 2023, p. 430).

FAA's conceptualization of safety culture, both for the companies it regulates and itself, has been influenced by Reason's (1997) conceptualization of an "informed" culture and its four critical, interrelated subcomponents: a reporting culture, a just culture, a flexible culture, and a learning culture. From a safety perspective, great weight is placed on employees feeling free, if

not obligated, to speak out about incidents or issues, even if they have made a mistake or violated a procedure. Creating this environment for openness requires ensuring that employee-reporters will not be punished or reprimanded for unintentional mistakes or violations. It also requires that (a) organizations focus on learning from mistakes, including building non-punitive reporting and information systems that inform decision making and (b) are flexible enough to change when processes or procedures are helping to create errors or not adequately minimizing them.

Influenced by the views of anthropologist Geert Hofstede (Reason, 1997, p. 194), Reason's view of safety culture is rooted in what it "has" and "does" (Schein's artifacts and espoused beliefs and values) and less so on what it "is" (Schein's shared assumptions). Reason's emphasis on the "having" and "doing" dimensions of safety culture has been embraced in definitions of the essential traits of organizational safety culture by national and international regulatory bodies.

The recent formulation of safety culture traits by the International Atomic Energy Agency (IAEA) is a modest re-wording of an earlier policy statement by the U.S. Nuclear Regulatory Commission (IAEA, 2020; Nuclear Regulatory Commission, 2011) (see Table 4-1). While recognizing that theorists and organizations vary in their definitions of safety culture traits and emphasis on them, an extensive body of research supports the traits defined by a committee of the National Academies of Sciences (NASEM, 2016). Recent AVS research reports on safety culture (Key et al., 2023; Worthington et al., 2023), as well as the culture survey AVS used in 2023–2024, have relied heavily on the IAEA 2020 formulation.

TABLE 4-1 Safety Culture Organizational Traits

1. Leader Responsibility	Leaders demonstrate a commitment to safety in their decisions and behaviors. Leaders are role models for safety.
2. Individual Responsibility	All individuals are personally accountable for safety. All individuals feel it is their duty to know the standards and expectations and rigorously fulfill those standards and expectations. There is personal ownership for safety. They have a commitment that promotes safety both individually and collectively.
3. Problem Identification and Resolution	Issues potentially impacting safety are systematically identified, fully evaluated, and promptly resolved according to their significance.
4. Decision Making	Decisions are systematic, rigorous, thorough, and prudent. Leaders support conservative decisions and the ability to recover quickly from unforeseen circumstances. Leaders follow the decision-making process. Responsibility for decision making is clear.
5. Work Planning	The process of planning and controlling work activities is implemented so that safety is maintained. Work is managed in a deliberate process in which work is identified, selected, planned, scheduled, executed, and critiqued. The entire organization is involved in and fully supports the process. All relevant parts of the organization work together to support the process of controlling work.
6. Continuous Learning	Learning is highly valued. The organizational capacity to learn is well developed. The organization employs a variety of approaches to stimulate learning and improve performance, including human, technical, and organizational aspects. Individuals and teams are highly competent and seek opportunities for improvement.
7. Raising Concerns	Personnel feel free to raise safety concerns without fear of retaliation, intimidation, harassment, or discrimination. The site creates, maintains, and evaluates policies and processes that allow personnel to raise concerns freely.
8. Communications	Communications support a focus on safety. Leaders use formal and informal communication to frequently convey the importance of safety. The organization maintains a variety of communication channels including direct interaction between

	managers and workers. Effective dialogue is encouraged. Effective communication in support of safety is broad and includes workplace communication, reasons for decisions and expectations.
9. Work Environment	Trust and respect permeate the organization. A high level of trust is cultivated in the organization. Differing opinions are encouraged, discussed, and thoughtfully considered. Employees are informed of steps taken in response to their concerns.
10. Questioning Attitude	Individuals remain vigilant for assumptions, anomalies, conditions, behaviors, or activities that can adversely impact safety and then appropriately voice those concerns. All employees are watchful for and avoid complacency. They recognize that minor issues may be warning signs of something more significant. Individuals are aware of conditions and alert to potential vulnerabilities

SOURCE: IAEA, 2020.

Assessment of Safety Culture

The committee's first report (NASEM, 2022) provides an overview of best practices in organizational culture assessment; these best practices, in turn, are more fully summarized in NASEM (2016) and IAEA (2019). In this report, the committee further emphasizes that culture assessment is an ongoing process that involves management engagement with employees through surveys, focus groups, dialogue, interviews, and other means of probing and understanding how organizational mindfulness and commitment to safety permeates and varies across an organization. Culture or climate surveys are often popularly believed to represent culture, which they can only do at a surface level and at a specific moment in time. Moreover, the metrics such surveys generate are "the least important aspect of culture assessment and change" (NASEM, 2016, p. 150). Their primary benefit is to "prompt conversations about and broaden understanding of the organization's safety processes, as well as [senior leadership and employee] participation in generating innovative paths forward and continuing conversation to learn from these efforts" (NASEM, 2016, p. 150, citing Carroll, 2015).

AVS Culture Assessment 2022

The initial survey instrument that AVS used was the Human Synergistics' Organizational Culture Inventory (OCI), a representation of organization culture based on a definition of culture as "the shared beliefs and values guiding the thinking and behavioral styles of its members" (Cooke and Rousseau, 1988). Thus, the OCI is a general-purpose survey of organizational culture, not a safety culture survey *per se*. The OCI is described as an instrument for assessing:

> 12 sets of norms that describe the thinking and behavioral styles that might be implicitly or explicitly required for people to "fit in" and "meet expectations" in an organization or organizational subunit. These behavioral norms specify the ways in which all members of an organization—or at least those in similar positions or locations—are expected to approach their work and interact with one another. (Cooke and Szumal, 2000)

Organizations are assumed in the OCI to have clusters of 12 norms and behaviors that can be bundled into Constructive, Passive/Defensive, and Aggressive/Defensive categories. The OCI is designed to estimate how organizational perceptions and behaviors are distributed across and within these three dimensions. Senior managers or organizations using the OCI can use this three-part construct to define their ideal organizations, which can be compared to how employees view the organization as indicated from results from the survey.

AVS staff briefed the committee on the results of the OCI in September and October 2023. The survey was conducted during the month of September 2022 by Human Synergistics and achieved a 30% response rate. The results of the OCI survey suggested that the staff viewed the organization as more "Passive/Defensive" and less "Constructive" than senior managers' aspirations for the organization. AVS subsequently used focus groups to probe more deeply into employee perceptions but did not have the results of that process at the time of the 2023 briefings.

Although widely used by many other organizations to assess culture, the OCI does not directly measure specific safety culture traits such as those listed in Table 4-1. Translating the results of a general culture survey to one that focuses on the specific safety-related values and behaviors of safety culture requires a considerable inferential leap to map the values and behavioral styles the OCI measures against the values and behaviors that organizations 'safety culture would reflect.

At AVS's request, Human Synergistics appended 13 questions to the standard OCI. Ten of these questions probed employee perceptions about AVS's openness to, and encouragement of, AVS employees reporting safety concerns, doing so without blame or recrimination, existing mechanisms for reporting, and management responsiveness to reports. These questions addressed employee perceptions of Reason's "reporting and just culture"; only three questions focused on AVS's "flexible and learning culture." AVS officials indicated to the committee that some respondents found the formal OCI survey to be lengthy and they had difficulty understanding the relevance of the questions to their work and the working conditions in AVS.

AVS has decided against using the OCI for its second annual safety culture assessment and rely instead on a set of questions designed to address safety culture traits directly. The committee views this as appropriate. Although undue importance should not be placed on the survey element of culture assessment, starting with a survey of employee perceptions based on key organizational safety culture traits is likely to lead more directly to insights about the strong and weak aspects of organizational safety culture.

AVS Safety Culture Assessment 2023

For the 2023 survey stage of its safety culture assessment, FAA tasked experts at its Civil Aerospace Medical Institute to develop a survey based on the 10 IAEA traits along with a few supplemental questions drawn from other relevant sources, such as the IAEA safety culture perceptions survey (IAEA, 2017) and an organizational culture survey used by the Nuclear Regulatory Commission (Nuclear Regulatory Commission, 2020). The speed with which the second AVS survey was developed precluded extensive psychometric testing, but the committee's review of the questions indicates face validity with the IAEA traits. Following considerable outreach from senior management as well as from the neutral third party that conducted the survey (to ensure anonymity), AVS employees were invited to participate and given four weeks to respond (October 12 and November 9, 2023). The total questionnaire had more than 80 questions, but in an effort to improve the response rate, respondents were randomly given a total of 20 questions, with each IAEA trait being addressed with two questions. On average, employees were able to complete the survey in less than 8 minutes.

AVS officials briefed the committee on the general results on March 11, 2024. The overall response rate reached 37%, which represented a 7 percentage point improvement over the 2022 survey. AVS officials indicated this response rate approached the 40% normally experienced in surveys of federal government employees, but they also acknowledged that it fell

well short of the 70% or more achieved in the safety culture surveys conducted periodically by the Nuclear Regulatory Commission (Nuclear Regulatory Commission, 2020). Responses were anonymous, but the demographic information provided suggests that the distribution of respondents across frontline and management positions was consistent with that of the AVS workforce. The general results of the survey as interpreted by AVS officials indicated that AVS employee commitment to safety is evident in the behaviors and work practices of individuals.

Furthermore, individuals adhere to established standards (i.e., policies, processes). AVS also appears to have a strong "just" and "reporting" culture. Employees feel free to speak up without fear of retribution. In terms of being a "learning" culture, AVS officials pointed to areas needing improvement in the IAEA traits of "communications" (leadership explaining reasons for decisions) and "continuous learning" (better sharing of lessons learned and in use of results to make improvements in safety oversight). Regarding AVS's overall safety culture, there are also opportunities for greater "leadership responsibility" (greater visibility of senior leaders as role models in their commitment to safety). Regarding AVS's "flexible" culture, officials expressed uncertainty about the amount of flexibility available to AVS given that its oversight derives from specific rules derived from its legislated authority and the limits of its resources. Plans for follow-up to respondents were in review by senior management at the time of the briefing.

REGULATORY SAFETY CULTURE

The International Atomic Energy Agency (IAEA)[29] investigation of the Fukushima Daiichi disaster implicated the culture of Japan's primary nuclear safety regulator as contributing to the multiple failures that occurred in preventing, mitigating, and responding to the massively disruptive earthquake and tsunami of 2011 (IAEA, 2015). The Nuclear Energy Agency (NEA)[30] subsequently set forth an initial set of principles and attributes of regulatory safety culture (NEA, 2016). This section explores possible lessons AVS could draw from this relatively new concept and the status of research about how it could be assessed.

Drawing from Leveson's (2023, pp. 640–657) review, five relevant threats to NISA's effectiveness in anticipating and preventing the Fukushima disaster include (a) a lack of independence from industry, (b) unwillingness or inability to act decisively in response to credible warnings, (c) inadequate staffing, (d) insufficient technical competence, and (e) complacency due to an "unrealistic risk assessment and reliance on redundancy."

Safety Culture Principles and Attributes for Regulators

The NEA's 2016 report, based on insights of experts and nuclear regulators from several nations, set forth an initial set of principles and attributes for the safety culture of nuclear regulators (see Table 4-2). This guidance follows the authors' recognition that, if regulators expect the

[29] The IAEA is a United Nations (UN) agency created in 1957 to work with UN member states and stakeholders worldwide promote "safe, secure, and peaceful nuclear technologies." See https://www.iaea.org/about/overview/history.

[30] The NEA is an advisory organization representing nuclear power regulators from 31 nations that operates under the auspices of the Organisation for Economic Co-operation and Development (OECD). See https://www.oecd-nea.org/jcms/tro_5705/about-us.

organizations that they regulate to have good safety cultures, regulators have to understand and model safety culture principles and behaviors themselves.[31]

TABLE 4-2 Principles and Attributes of Regulator Safety Culture

Principles	**Attributes**
1. Leadership for safety is to be demonstrated at all levels in the regulatory body.	(a) "Safety first" is a guiding principle in the regulatory body. (b) All leaders throughout the regulatory body demonstrate a commitment to safety in their decisions and behaviors. (c) Leaders create an environment for positive development of the safety culture. (d) Leaders clearly define individual roles, responsibilities, and authority. (e) Leaders ensure that the necessary resources are available to meet the safety mission.
2. The culture of the regulatory body promotes safety and facilitates cooperation and open communication.	(a) Personal commitment to and accountability for safety from every staff member, at all levels of the organization. (b) A strong sense of collaboration and co-ordination of activities across the organization. (c) The need for moral courage and agility in doing the right thing.
3. All staff of the regulatory body have individual responsibility and accountability for exhibiting behaviors that set the standard for safety.	(a) Openness and transparency. (b) Clear organizational commitment to co-operation. (c) A questioning attitude, and mechanisms to raise differing opinions on regulatory decisions. (d) Promotion of safety and associated knowledge.
4. Implementing a holistic approach to safety is ensured by working in a systematic manner.	(a) A healthy respect for the consequences of all actions and decisions taken by the regulatory body. (b) Clear awareness of roles and responsibilities in relation to licensees. (c) A clear regulatory framework. (d) Proactivity, adaptability and a holistic approach. (e) Recognition of the complexity of safety issues.
5. Continuous improvement, learning and self-assessment are encouraged at all levels in the organization.	(a) Looking at ourselves in the mirror: safety culture self-assessment and peer reviews. (b) Learning from experience, fostering exchanges and increasing knowledge. (c) Knowledge management to build a healthy safety culture. (d) Continuous improvement as a clear value of the regulatory body.

SOURCE: NEA, 2016. CC BY 4.0.

Fleming, Harvey, and Bowers (2022) further refined the NEA list of regulatory culture principles in their effort to develop a survey instrument that regulators could use to initiate assessment of their safety cultures:

1. Leadership commitment to creating a positive safety culture;
2. Unwavering ethical standards;
3. Transparency through communication;
4. Proactive risk informed approach;
5. Continuous learning and self-improvement.

[31] IAEA guidance to regulatory self-assessment accepts this conclusion, but its recommended practice for regulatory self-assessment nonetheless appears to rely on a survey instrument that it also recommends for use by nuclear power plant operators (IAEA, 2019).

Fleming, Harvey, and Bowers's list overlaps with that of the NEA but gives greater emphasis to their principle 2 of "unwavering ethical standards," which they interpret to include regulator independence, compared to the NEA attribute 2.c of "moral courage" and "doing the right thing." Their principle 4 substitutes "proactive risk-informed approach" for the NEA's principle 4 of "implementing a holistic approach." Both lists overlap with most of the IAEA safety culture traits for operators, but also indicate different levels of emphasis more appropriate for regulators than operators. For example, the IAEA trait 5 regarding the planning of work is appropriate for operators directly managing the hazards associated with their work, whereas the NEA attribute 4.c for a "clear regulatory framework" would document what regulators expect to see in the organizations they are regulating and, presumably, as well, what they will do to assure that the entities they regulate are doing what is expected of them.

Regarding the regulatory culture failures associated with the Fukushima disaster, NEA attribute 1.e is the only one that speaks directly to leaders ensuring that adequate resources are available to carry out the regulator's safety mission. Although it may be implicit in the overall construct of the NEA's principles and attributes, they do not speak directly to the independence of the regulator or to its technical competence. The AVS 2023 safety culture survey questions, although they could be more pointed, out of the five NISA failures, address elements of four: independence (in the sense that decisions reflect safety regardless of industry or other pressures), competence (the emphasis is on training, which is a necessary but not sufficient condition for competence), resource adequacy, and questioning attitude. The Fleming, Bowers, and Harvey initial survey instrument, discussed next, also covers four of the five indicated NISA failures. Although they appear to be implied, the ability and willingness of the regulator to take decisive action in response to an existing or potential emerging hazard is not addressed directly in any of the regulator culture constructs proposed to date.

Regulator Culture Assessment

Fleming, Harvey, and Bowers's aim was to develop a psychometrically tested survey instrument for regulators since none of the ones developed for regulators have applied this technique to help ensure quality. They began by evaluating the three then-existing models of regulator behavior they were aware of (Bradley, 2017; Fleming and Bowers, 2016; NEA, 2016). With the help of 13 nuclear power industry safety culture experts, Fleming, Harvey, and Bowers organized the principles and attributes into 11 dimensions (see Box 4-1).[32]

BOX 4-1
Hypothesized Dimensions of Regulator Safety Culture

1. Leadership Actions
2. Regulator Independence
3. Responsibility and Accountability
4. Continuous Learning, Improvement, and Competence
5. Questioning Attitude

[32] Note that in 2019 the Safety Management International Collaboration Group (SMICG) developed its own instrument for "initial" aviation regulator self-assessment (SMICG, 2019, Appendix 1). The 40-item survey appears to cover some of the same dimensions as indicated in Table 4.3, but the theory or principles on which the survey was developed are not explained. The SMICG does recognize that assessment requires far more than a survey.

6. Ethics and Moral Courage
7. Psychological Safety
8. Systematic Regulatory Approach
9. Decision Making
10. Inter-disciplinary Internal Cooperation
11. Openness, Transparency, External Cooperation, and Communication

SOURCE: Fleming, Harvey, and Bowers, 2022.

Working with 14 other safety culture experts, Fleming, Harvey, and Bowers (2022) developed and tested a 71-item survey instrument using an initial convenience sample of 114 international regulatory staff. However, after factor analysis of survey results, six theoretically important dimensions were not correlated, leadership, ethics and moral courage, independence, interdisciplinary internal coordination, decision making, and questioning attitude. The lack of correlation with such key safety culture dimensions led the authors to recommend use of a random sample of a larger set of respondents to better ensure valid results. At the time of this writing in early 2024, the concept of regulatory safety culture is still in a nascent state with relatively little research and analysis to support it (Fleming, Harvey, and Bowers, 2022). However, the committee believes the regulatory safety culture concept has promise and encourages AVS to study and learn from the regulatory failures at Fukushima as well as other cases involving regulatory inadequacies, such as the *Deepwater Horizon*/Macondo well disaster of 2010 (NAE and NRC, 2012). AVS could also monitor and learn from the ongoing efforts to develop the regulatory safety culture concept and a self-assessment instrument for it.

Findings and Recommendations: AVS Safety Culture Assessment Including Regulatory Safety Culture

Finding 4-1: The committee supports the AVS shift in 2023 to a survey based on the 10 IAEA safety culture traits and its efforts to improve the response rate. The appointment by AVS of a manager with experience in the safety culture assessment process is appropriate. These steps represent good progress, although the committee observes that the congressional request for the annual assessment of the AVS safety culture was enacted in December 2020; while the second survey had been completed at the time of the committee's briefing in March 2024, the overall second annual assessment was incomplete.[33]

Finding 4-2: A safety culture survey represents but the initial step in an ongoing dialogue and discovery process between senior management and employees about the safety culture of an organization and how it can be strengthened. For the committee to carry out its charge of reviewing AVS's annual safety culture assessment requires greater insight into the steps being taken by AVS to assess its culture beyond the survey and how it is using what it is learning to strengthen the AVS safety culture.

[33] In its mandate that AVS conduct an annual safety culture assessment in December 2020, Congress specified that the assessment include an annual survey of AVS employees. The committee's charge is to review the annual safety culture of AVS mandated in P.L. 116-260, Division V, Sec. 132. The scope of its review does not include other FAA organizations.

Finding 4-3: Success in strengthening the AVS safety culture depends heavily on the direct, visible, and frequent engagement of senior AVS management with front line employees in enabling, enacting, and elaborating the AVS safety culture. These are not responsibilities that can be delegated to the manager responsible for the safety culture survey. At the time of this writing, the committee lacks evidence about such a level of engagement by the highest levels of AVS management in learning from safety culture assessment and implementing actions aimed at strengthening AVS's safety culture.

Finding 4-4: The emerging concept of the safety culture appropriate for a regulator reflects the view of the IAEA that, if regulators expect the organizations that they regulate to have good safety cultures, they have to understand and model safety culture principles and behaviors themselves. To date, there is insufficient research in defining, and distinguishing between, the traits and behaviors of the safety cultures of regulators and the safety culture of those they oversee. The emerging concept of regulatory safety culture is one that AVS can monitor and learn from. Moreover, FAA could support the development of this concept and its assessment through its research budget.

Finding 4-5: The safety culture of any large organization does not change quickly. An annual survey is too frequent to pick up shifts in employee perspectives about the organization's safety culture. (The Nuclear Regulatory Commission conducts a survey every 3 to 5 years.) The ongoing assessment process of the AVS safety culture can also employ appropriate cycles of other processes, such as focus groups, ongoing dialogue with front-line employees, and input from the employee voluntary reporting system can help AVS articulate and mature its safety culture.

Recommendation 4-1: Congress should continue requiring the Federal Aviation Administration Office of Aviation Safety (AVS) to assess its safety culture, but allow AVS the flexibility to reduce the frequency of the safety culture survey, and in alternate years allow AVS to focus more of its annual assessment efforts on formal and informal communication by leadership, conduct of focus groups and other forms of dialogue with employees about their perceptions of AVS's safety culture, and feedback to employees about what leadership is learning through the assessment process and the changes it is making in response. Within this process, AVS should identify two or three major goals the organization has for strengthening its safety culture and a short list of actions it will be taking, and evaluating in the next assessment, to help achieve these goals. Likewise, AVS should identify the safety culture traits and behaviors it should model as a regulator to the industry organizations it oversees.

The committee, in its next study, will continue with its required review of AVS safety culture assessment, and will incorporate these items.

Recommendation 4-2: The safety culture assessment manager that Federal Aviation Administration (FAA) Office of Aviation Safety (AVS) has added to its staff should report regularly to the AVS Associate Administrator and the FAA Administrator,

both of whom should be responsible for appropriate actions to enable a strong, and continuously improving, AVS safety culture.

MATURING SAFETY CULTURE ACROSS THE INDUSTRY

Innovation may ultimately bring societal benefits. However, such innovations may stress current industry with changes in business model and changes from their historic products and operations; likewise, innovators may include new entrants who, as noted in Chapter 1, may not have an organization and culture steeped in aviation safety. The very deeply embedded assumptions and behaviors (Schein, 2010) that make an entrepreneurial new entrant successful in product development may be counter to what is required to achieve FAA certification and operational approval.

However, organizational cultures can be steered to improve, as described in the next three parts of this section:

- Safety culture maturity;
- Regulator role in safety culture maturity; and
- New entrant safety management and metrics and implications for AVS oversight.

Safety Culture Maturity

The safety culture maturity concept (Fleming, 2001; Parker, Lawrie, and Hudson, 2006; Westrum, 1993) illustrates stages of organizational safety culture maturity, which range from being uncommitted to safety to integrating safety into everything that an organization does. The safety culture maturity concept is not a predictive model nor, in itself, a specific guide to action. Rather, it can help people recognize that cultures vary along the dimensions of maturity it describes, use this concept to help them assess their organizations' cultures, and illustrate how organizations' safety cultures can grow through deliberate actions on the part of leaders and employees. However, it is simplified by its implication that organizations have monolithic cultures. In fact, organizations have subcultures that differ across levels and professions (Schein, 2010). The culture of large organizations also likely differs across divisions and regional offices. Moreover, the stages that organizations are depicted to move through do not necessarily progress upward. Organizations can regress due to a change, or lack of, leadership or they can simply become complacent about the presence of latent conditions that, in combination with local conditions, can penetrate layers of defense (Reason, 1997). Progression up the maturity ladder, and even maintenance of an organization's place on the ladder requires active engagement by management and employees. That said, the maturity concept is a useful heuristic for representing how safety cultures can grow stronger and how regulators can influence that process.

The stages of safety culture development postulated by Parker, Lawrie, and Hudson (2006) build on the work of previous scholars and have since been modified by many others and applied across multiple safety-critical industries (Filho and Waterson, 2018). The descriptions of the maturity stages below draw on Hudson (2001) and Parker, Lawrie, and Hudson (2006) and have been modified to apply to the commercial aviation industry.

Pathological: Companies at this stage lack any real commitment to safety, as indicated by its name (see Figure 4-1). This category was included as a benchmark, highlighting organizations that lack the requirements and expectations that exist in commercial aviation.

Reactive: An organization that is reactive with regard to safety implies that its communications are mostly top-down; management believes failures are caused by individuals; incident information is being gathered but not necessarily volunteered and procedures changed in response but without follow-up; regulations are implemented but without strong commitment; and management statements about safety are not always believed by the workforce.

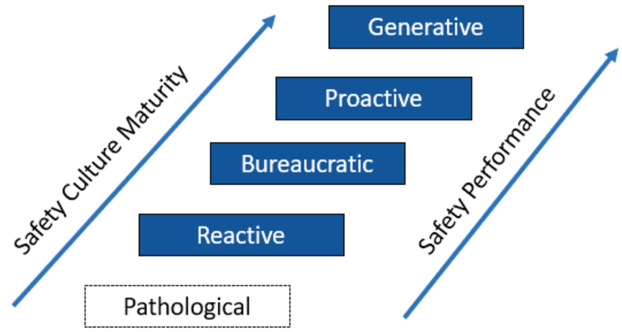

FIGURE 4-1 Safety culture maturity ladder.
SOURCES: Parker, Lawrie, Hudson, 2006; SMICG, 2019.

Bureaucratic: In this stage, management is exercising top-down control of safety but with little bottom-up information about what might be going wrong; the workforce is becoming more involved in items such as improving procedures and reporting incidents but receives little feedback from management; a safety officer is collecting and reporting statistics to management and developing standardized procedures but with few checks on their use or employee understanding of them; safety indicators are increasingly quantitative but may not be measuring actual risk.

Proactive: In the proactive stage, management engagement in safety is more visible and tangible to the workforce; information is flowing back and forth between senior management and the front line; safety discussions are permeating into other meetings; the workforce is more engaged; procedures are rewritten with input from employees; training is complemented with measures to determine competency; safety is given high priority; the safety director has a high-status role in advising top management; frequent discussions are held across the organization about near misses and their proximate, organizational, and cultural causes and how to reduce them; and emerging hazards are being identified and monitored, and corrective actions taken.

Generative: The generative stage may be more aspirational than common, but at this stage safety would be fully incorporated into all decision making and behaviors, and the organization is committed to continuous improvement in all phases of its safety management and performance. Indicators of such maturation would be that of an organization fully dedicated to learning through communication and information flowing freely across the organization; hazards being anticipated and managed before they result in incidents; management and the workforce working in effective partnerships; and employees at all levels actively resisting complacency by constantly focusing on what might go wrong, which Reason (2000) also described as a mindset of “intelligent wariness.”

One would not expect new entrants that are developing and proposing new technologically based aviation services to be prepared to operate systems safely at the proactive stage of cultural maturity. However, having a well-conceived set of safety policies, procedures, operating plans, and SMS, including generating and sharing information with FAA demonstrating effective safety management, could be conditions FAA places on allowing new entrants to test their proposals and ultimately begin to implement them (if successful) and expand them (if warranted) through demonstrated safety performance. This is part of the additional data collection and analysis needing to be built into the safety assurance component of safety management discussed in the previous chapter.

Regulator Role in Safety Culture Maturity in the Industry

One approach for maturing a new entrant' safety culture would be through collaboration and coaching from FAA, a role recommended by the Safety Management International Collaboration Group (SMICG) (2019).[34] For a regulator to do so effectively, it would need to understand what a mature safety culture is, be fully cognizant of how its culture and behaviors are influencing the operators it regulates, and have sufficient competence in assessing the culture of operators and influencing them effectively. A regulator that is itself at the bureaucratic stage of maturity and reliant on prescriptive authorities and regulations may struggle to help operators mature beyond this stage.

In 2020 the U.S. Department of Transportation Office of Inspector General (OIG) faulted FAA for not providing its aviation safety inspectors with guidance on how to "evaluate and oversee an air carriers' safety culture" (USDOT OIG, 2020). Given the vague dimensions of safety culture, and multiple approaches needed for assessing it, evaluating the culture of an operator through inspections alone would be beyond what a regulator could be expected to accomplish. Consistent with the guidance offered above and in the committee's first report, the SMICG (2019) recommends use of a full set of quantitative and qualitative methods (such as surveys, workshops, and interviews) to assess an operator's safety culture. However, AVS concluded that this level of assessment would (a) be too resource intensive for routine surveillance of certificate holders, (b) require specialized expertise, and (c) be inconsistent with FAA leadership direction in response to the OIG report to implement a method that was achievable by its existing workforce and could be incorporated into FAA's Safety Assurance System (SAS)[35] (Worthington et al., 2023).

AVS researchers therefore modified existing data collection tools in the SAS to prompt inspectors to record concerns about safety culture-related behaviors and activities across the seven organizational safety attributes used in the SAS.[36] They also recommended additional training for inspectors in safety culture (Worthington et al., 2023). The AVS approach may be sufficient to train inspectors to identify and record surface level indicators of a weak safety culture. The data entered into the SAS can be used by the principal AVS staff responsible for

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[34] The SMICG was founded by FAA, the European Union Aviation Safety Agency, and Transport Canada Civil Aviation. It is a joint cooperation between many aviation regulatory authorities for the purpose of promoting a common understanding of safety management and Safety Management System (SMS)/State Safety Program (SSP) principles and requirements.

[35] The SAS is FAA's risk-based, data-supported oversight tool used by AVS offices to carry out certification, surveillance, and continued oversight of operational safety. It contains policies, processes, and data collection tools that AVS can use to capture data when conducting oversight.

[36] Procedures, Responsibility, Authority, Controls, Interfaces, Process Measurement, and Safety Ownership.

certificate holders to trigger a formal evaluation. However, whether AVS has the collective expertise to assess safety culture is not obvious given that best practice in safety culture assessment is an ongoing process involving multiple methods (quantitative and qualitative). Instead, evaluation of an organization's safety management process and SMS may be a more tractable and promising approach.[37]

FAA Monitoring of Safety Culture Through Safety Management Systems

This chapter begins with the observation that an organization's safety culture will drive how well it can actively manage safety, and the practices required for safety management can serve as a learning process to mature that safety culture. Enabling, enacting, and elaborating can change culture through implementing, practicing, learning, and improving (Vogus, Sutcliffe, and Weick, 2010). The conditions AVS places on new entrant safety management and its monitoring of the new entrant's safety management processes would provide AVS opportunities to encourage organizational learning and safety culture maturity.

Insights from Safety Management into New Entrant Safety Culture

By their nature, new entrants are proposing to provide novel services with novel technologies by new organizations. As noted in the previous chapters, established criteria, measures and processes for both the safety risk management and safety assurance components of safety management cannot rely entirely on historic practice in aviation. Likewise, examining the organizational structure and culture components of safety management, new organizations may lack experience in structuring an organization to emphasize safety. The safety management plan proposed by a new entrant would provide FAA insight into how a new entrant proposes to address these safety issues and concerns, and then its execution would provide the data, analysis and process for change management and continuous improvement that FAA could use to assess how effectively they are addressing these concerns.

Evaluation of Proposed Safety Management Systems and Processes

AVS can analyze any applicant's proposed safety management plan by analyzing the descriptions of the components and elements of the SMS. In terms of organizational structure and culture, this assessment can include questions such as:

- How insightful the stated safety policy is, whether it was developed in concert with representatives of its workforce, whether it has all the necessary elements to allow for an "Informed Culture," and how management will communicate and reinforce this safety policy;
- How the new entrants' management commitment to the stated safety policy will be expressed through communications, resource allocation, and managers' evaluations and compensation;
- The experience, competence, seniority, authority, and access of the top safety official to senior leadership; and

[37] In this chapter, the committee relies on the ICAO (2018) SMS formulation, particularly the safety risk management and safety assurance processes of SMSs (see Figure 1 in Chapter 3).

- How the competence of the workforce would be maintained through training and testing for competence.

Execution of Safety Management

The information generated as part of safety management would guide new entrants' development of a safety culture, and the sharing of this information would provide AVS with insight into new entrants' commitment to safety management and safety culture. The data collected during safety risk management and safety assurance should also include indicators of organizational and cultural concerns, such as tolerance for routine operating errors; failures in carrying out procedures and policies or updating them in a timely way in response to employee feedback; and weakening and misalignment of organizational culture (differences in espoused and actual behavior). Other indicators that could be monitored include staffing levels, turnover, and competency records; resource allocation for training; task performance records; defect tracking systems; maintenance and repair effectiveness and backlog, internal and independent audits, missed audits, corrective actions taken, and missed deadlines in corrective action plans (CIEHF, 2016).

A framing for these risks must extend beyond just separating measures of the technology, of the operation of the technology, and of the organization: Macrae's (2021) framework, for example, defines and categorizes sociotechnical risks of autonomous and intelligent systems (AIS) and the multiple interactions among advanced technologies, organizational operations, limits in the understanding of AIS performance, and organizational culture (see Figure 4-2).

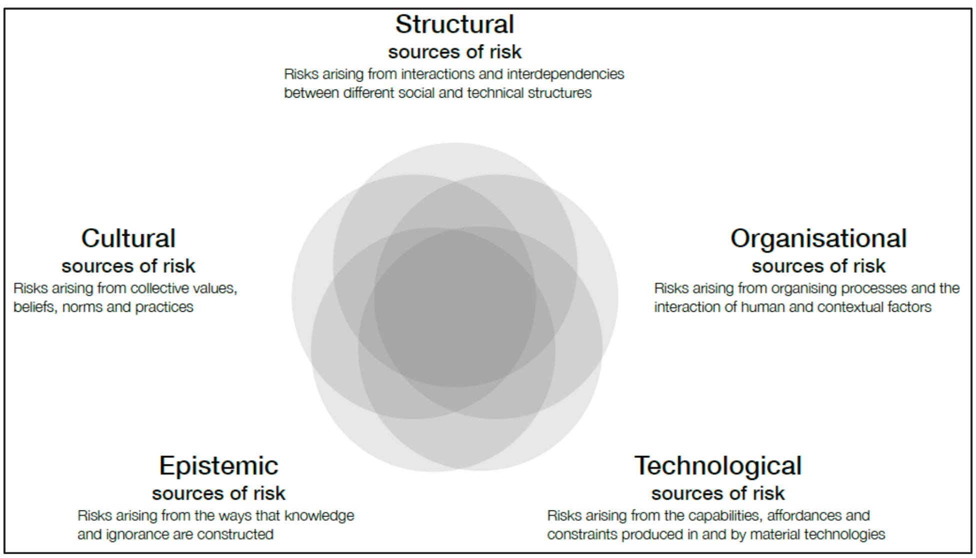

FIGURE 4-2 Framework for sociotechnical risk.
SOURCE: Macrae, 2021. CC BY.

Finding 4-6: The components of safety management, the data they generate, and their implementation in a SMS, can provide FAA with a primary mechanism for oversight of organizations 'safety culture maturity, how safety management will be integrated into operations and management by new entrants, and how safety management can be applied throughout the organization for continual improvement.

Finding 4-7: Promising safety indicators to support both industry organizational structures and safety culture and FAA oversight would include testing of employee competence in understanding and executing risk controls; feedback between front-line employees and system developers regarding identification and management of hazards; identification and response to unanticipated emerging hazards within the organization; results from employee voluntary reports, SMS audits, audit deficiencies, and corrective action plans and timeliness of response to them; and other indicators of the organizations preoccupation with what might go wrong and continual improvement.

The findings here on safety culture contribute to recommendations made in the next chapter, which discusses how safety management needs to be integrated across disciplines, organizations, and the lifecycle of new products and operations.

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5
Integrated Safety Management Across the Lifecycle and Across Organizations

The tasks of identifying, monitoring, understanding, and addressing emerging aviation safety risks cannot be fully achieved by only looking at separate aspects of the National Airspace System (NAS) and by applying sequential processes. The previous three chapters considered separately the details of the three aspects of Safety Management: safety risk management (Chapter 2), safety assurance (Chapter 3), and organization processes and culture (Chapter 4). However, safety is only effectively managed when these aspects of safety management are purposefully coordinated, and when they are integrated across the many organizations involved, the subject of this chapter.

First, the committee considered how safety now routinely spans multiple organizations at every stage of the lifecycle. During design, multiple different components from different suppliers may be assembled, and aspects of analysis may be contracted out to specialists; later design modifications may be conducted by yet other organizations (e.g., supplemental type certificates by third parties). During production, the "prime" manufacturer may outsource production of components, and supply chains may depend on parts and services from a fluid and evolving network of many third-party organizations. In such cases, safety requires more than just "quality assurance" by third-party suppliers to actively manage concerns with, for example, collectively modifying and evaluating component safety on the production line.

This need to coordinate multiple organizations also is important during the day-to-day operation: a "prime" organization such as a major air carrier may interoperate with many code-share and regional partners, and aircraft operators are supported by separate organizations providing safety-critical functions such as cargo handling, maintenance, and dispatch. The committee learned of even more transformative changes in how multiple organizations may interact from an industry presenter at a workshop, who is proposing to create a third-party service provider that, even during the flight, provides autonomous aircraft with time-critical data and calculations such as revised flight plans. In cases such as this, sensing and decision making currently assigned to a pilot and on-board systems will be distributed via communication links and cloud computing to span on-board systems, a remote pilot, a central operations control, and support service organizations outside the aircraft operator's organization.

An example of a gap between "prime" and supplier was in identified in the National Transportation Safety Board's (NTSB's) accident report for the 1996 accident of ValuJet 592,[38] in which a contractor, SabreTech, delivered 144 expired chemical oxygen generators without the proper caps over the generators' firing pins and improperly labeled in a manner interpreted by ValuJet workers that the canisters were empty and safe to transport. The canisters activated early in the flight and created an intense fire in the cargo hold, which ultimately burned through

[38] See https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR9706.pdf.

control cables, causing the aircraft to lose control and dive steeply into the Everglades. The NTSB determined that the probable causes of the accident included, first, SabreTech (for its overtly wrong actions) and, second, the failure of ValuJet to properly oversee its contract maintenance program, with the recommendation that "Part 121 air carriers 'maintenance functions receive the same level of Federal Aviation Administration surveillance, regardless of whether those functions are performed in house or by a contract maintenance facility."

This issue surfaced as a concern with established industry players. Even as the committee was examining it as a potential concern with new entrants in this study, very public displays of the impact of poorly coordinated outsourcing came to light with the Boeing 737-MAX9 door plugs. In this instance, significant components of the fuselage were manufactured elsewhere and shipped to the final assembly plant. Some of them arrived damaged; the repairs required removing critical bolts to access the damage, and safety required that these bolts be properly re-installed before the entire door plug was installed on the aircraft. In this transition between supplier and lead manufacturer, critical knowledge was dropped.

These concerns highlight that the prime organizations can outsource parts and labor, but they cannot outsource the safety risk these arrangements may bring to their product or operation. In all cases, risk may be added by any entity contributing to the product or operation if not systematically managed, and risk can be added by poor transfer of knowledge between the entities or poor coordination of their activities; either way, the resulting safety concern is an aspect of the assembled product or combined operation driven by the prime.

Safety risk management with out-sourcing in design and production raises several questions: how can the prime guarantee that delivered components were created according to its standards and integrate properly into the final product? How to guarantee that requisite knowledge (e.g., whether vital bolts were removed and/or replaced during the repair of an out-sourced component damaged in transit to the prime) is properly transferred between prime and subcontractor?

The other major components of safety management, safety assurance and organizational structures and culture, also face similar questions: How can a "prime" operator confirm that it is getting all the relevant data and insight from third-party organizations supporting its operations? Can and should it require the same data from these other organizations, for example, and how should these organizations be involved in analyzing and interpreting this data? If a "prime" works deliberately and pervasively to foster safety within its organization, what can and should it require of their third-party suppliers and service providers?

> Finding 5-1: Safety cannot be regulated by examining only the safety management processes of a prime organization that involves third-party suppliers or service providers in support of their design, production or aircraft operation; likewise, it is not sufficient for the regulator to oversee each organization separately. Instead, the prime organization's decision to involve others, including purchasing their products and services, requires a deliberate, layered approach to safety management that ensures all contributions together comply with their safety risk management and safety assurance processes, and are based on appropriate organizational processes and culture. The regulator has the role in overseeing that this layered safety management is implemented and continuously monitored and used to manage safety across all constituent organizations.

Recommendation 5-1: The Federal Aviation Administration Office of Aviation Safety should establish the personnel, mechanisms, and policies that enable oversight of effective layered safety management of an organization applying for certification, ensuring that this safety management also spans the contributions of those third parties whose products and services contribute to safety. This oversight must ensure that this layered safety management is not only implemented correctly at the time of initial certification but also continuously applied.

A second aspect of integrated safety management addresses how it is deliberately and effectively handled across the lifecycle—that is, safety risk management starting in the earliest stages of design and continuing through manufacturing and implementation, and then continuing into safety assurance during operation (including not only flight but also ongoing maintenance, modifications, and improvements). For many products such as aircraft, this lifecycle can span decades, involve substantial modification to the design and its use in new flight profiles and operations, and involve organizations that are uncoordinated (e.g., operating an aircraft manufactured decades before by a company that no longer exists). The previous chapters noted key touchpoints in safety management at distinct points the lifecycle, including:

- The safety assurance processes applied once a new technology or operation is implemented can be bolstered by knowing the key assumptions and reference points used earlier in safety risk management.
- Furthermore, safety assurance can challenge key assumptions and reference points upon which earlier safety risk management was based, triggering a reiteration of the safety risk processes, which then should inform an update for the plans for safety assurance.
- Throughout, effective safety risk management and safety assurance practices depend on organizational processes and culture.
- Likewise, ongoing evaluations during safety risk management and safety assurance can also be used to measure and inform continuous improvements to organizational processes and culture.

Finding 5-2: Often, the entities that seek to certify products, to certify personnel, and to operate and maintain aircraft are separate, uncoordinated organizations, and they may be active at very different points in time. Safety is bolstered when each entity, at the time of its activity, is expected to capture the data and knowledge that informs safety management by those reasonably expected to use the same technologies or operations after them.

RECOMMENDATION 5-2: The Federal Aviation Administration Office of Aviation Safety should identify and characterize the data and knowledge associated at each stage in designing, testing, maintaining, and operating aircraft that then can be useful to safety management later in the life of the product or operation. This data and knowledge should be required to be captured at the time, and later integrated into subsequent activities in support of both safety risk management and safety assurance.

The committee started researching this report out of a concern for safety management in the face of transformative changes in technologies and operations, often involving new entrants. However, the final drafting of this report is colored by recent events highlighting how safety amongst even the most established technologies and players in the industry can be vulnerable to any lapse in safety management. A key question for managing both established and emerging safety concerns the role of the regulator. Unlike the popular conception of FAA as the technical expert who provides final, definitive assessments of a product's or person's safety to fly, aviation is such an immense undertaking in scale, compounded by safety also requiring incredible attention to detail, that FAA cannot be expected to directly oversee all aspects of design, production, personnel, and operations. Instead, this chapter posits safety management as the process that FAA should ensure is properly occurring longitudinally across the life of products and operations, and also across organizations.

Finding 5-3: Recent events suggests that AVS may already be challenged to regulate all aspects of the NAS. Transformative changes will further pose challenges with managing new risks. To address both current and likely future technologies and operations will require adequate funding and staffing, and requires this staff has requisite technical expertise across the full spectrum of technologies. Furthermore, AVS staff must have the training and vision to oversee broad safety management processes spanning the life of a product (design, production, and operation), spanning multiple organizations, and considering the organization structures and culture needed in these organizations that they oversee.

Recommendation 5-3: The Federal Aviation Administration Office of Aviation Safety should evaluate its personnel requirements in light of the demands placed on the workforce in identifying and addressing both existing and emerging risks. Emphasis should be placed on expertise required to oversee and evaluate new and emerging technologies and operations, to oversee the transition from safety risk management to safety assurance as new technologies and operations are implemented, to support the maturation of safety culture within the industry organizations it oversees, and to ensure rigorous safety management processes within all the contributing organizations that impact aviation safety.

Henry Petroski, in evaluating the evolution—and failures—of technology in many domains, coined the phrase "to engineer is human" (Petroski, 1992). Even when all is properly regulated and evaluated in best faith to the extent suggested by human understanding, any first-time implementation represents a new frontier in knowledge in which the unexpected can manifest subtly or suddenly and violently. In aviation, even reasonably small changes to otherwise-solid systems have a history of the unexpected occurring, such as the battery thermal runaways when Boeing aircraft transitioned to more powerful lithium-ion batteries to support increased use of electrical components across the aircraft.

Transformative changes in technology and operations reflect an even larger step-function change in the knowledge that is required to design systems and operations safely, and even to know what tests and monitoring to run. Each transformative change represents a step-change in knowledge—and each of these step changes may have gaps in this knowledge that are undetectable and inscrutable until later, with experience. Thus, it is important to constantly

understand that, even after the best safety risk management process before implementation, something unexpected may happen once something new takes flight.

A seminal discussion of high reliability organizations noted:

> Perhaps the most important distinguishing feature of high reliability organisations is their collective preoccupation with the possibility of failure. They expect to make errors and train their workforce to recognise and recover them. They continually rehearse familiar scenarios of failure and strive hard to imagine novel ones. Instead of isolating failures, they generalise them. Instead of making local repairs, they look for system reforms. (Reason, 2000)

Finding 5-4: The aviation industry, and FAA in all its roles, should remain vigilant for emerging safety risks as new technologies and operations are implemented—to detect the precursor before it manifests as an accident, to investigate unexpected behaviors and effects to characterize their safety and risk, and to be open-minded and prepared to seek new mitigations to newly identified risks.

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6
Conclusions

Safety management is never finished—it must be continually applied to identify and address emerging concerns in aviation safety. Furthermore, all aspects of safety analysis: the metrics and methods for identifying and addressing risks, the data gathered, the processes for analyzing data, and organizational structure and culture, must themselves be constantly reviewed and updated to address new challenges. This report focuses on transformative changes to technologies and operations, and the new entrants that often propose them, that cannot simply just apply current methods for safety management. "Transformative changes" are defined here as changes that are sufficiently novel that their impact on safety and risk cannot be extrapolated from current data and analysis methods. Such changes are highlighted in the potential systemic stressors noted in the first report with "new entrants" and "new technologies and operations."

First, the committee examined how to identify and address emerging safety concerns with transformative changes to technology and operations. Second, the committee noted that, while extensive data-gathering activities support monitoring of current concerns, gaps exist in data and analysis methods for predicting new hazards that may emerge with transformative technologies and operations; similarly, methods for predicting and then continuing to monitor for safety concerns are vital to the safe implementation of transformative changes to technology and operations. Third, this report follows up on the committee's previous finding that the Federal Aviation Administration (FAA) Office of Aviation Safety (AVS) assessment of its internal safety culture was, at the time of the first report, in a formative state requiring further development and review; this report extends its discussion of safety culture to the question of how to foster and regulate safety cultures within the industry, particularly with new entrants.

This report frames its analysis using the established principles applied in aviation safety management. Safety management occurs across the entire lifecycle of technologies and concepts of operation, from their design, through their implementation via production, operations, and maintenance. Such safety management spans multiple processes, including (1) safety risk management processes before new technologies and operations are implemented, to identify hazards, assess their risk, and implement appropriate safeguards and mitigations, largely focusing on certification and regulatory approval before implementation; (2) safety assurance processes once new technologies and operations are implemented via ongoing data collection and analysis to support continuous improvement; (3) safety policy and objectives determining the high-level properties of the organization integrating a commitment to safety; and (4) safety promotion across all levels of the organization. Chapters 2 through 5 provide detailed findings and recommendations on these topics.

THE OVERARCHING FINDING: NEW CONCERNS ALWAYS EMERGE

This report reflects the committee's tasking to identify, categorize and analyze emerging safety trends in air transportation, including offering advice to Congress, FAA, industry, and others on options for improving means for identifying, monitoring, understanding, and addressing emerging aviation safety risks. Throughout its activities, the committee relies on a definition of "emerging" that refers to something "becoming apparent or prominent." Thus, the committee interprets emerging trends in safety to include both new hazards emerging via proposals for new technologies or operations, as well as current concerns that may be becoming prominent.

Even when all is properly regulated and evaluated in best faith to the extent suggested by human understanding, any first-time implementation represents a new frontier in knowledge in which the unexpected can manifest subtly or suddenly and violently. In aviation, even reasonably small changes to otherwise-solid systems have a history of the unexpected emerging. Transformative changes in technology and operations reflect an even larger step-function change in the knowledge that is required to design systems and operations safely, and even to know what tests and monitoring to run. Each transformative change represents a step-change in knowledge – and each of these step changes may have gaps that are undetectable and inscrutable until they emerge later, with experience. Thus, it is important to constantly understand that, even after the best safety risk management process before implementation, something unexpected may happen once something new takes flight.

Thus, the aviation industry, and FAA in all its roles, should remain vigilant for emerging safety risks as new technologies and operations are implemented—to detect the precursor before it manifests as an accident, to investigate unexpected behaviors and effects to characterize their safety and risk, and to be open-minded and prepared to seek new mitigations to newly identified risks. (F5-4)

GAPS IN THE STATE OF THE ART ON AVIATION SAFETY MANAGEMENT

Chapters 2 through 5 detailed a range of concepts in safety management. Some of their associated findings and recommendations highlight relatively straightforward actions that FAA and Congress should undertake, reflecting the state of the art. However, some findings and recommendations highlight where further research and knowledge is required. Commercial aviation is at the forefront of safety, to the extent that it cannot simply learn from other industries, or at least would need to purposefully tailor methods proposed in the scientific literature to apply them to aviation's unique needs.

The discussion of safety risk management in Chapter 2 highlighted two such gaps. First, the call for increased use of performance-based standards (Finding 2-3 and Recommendation 2-3) requires conceptual understanding of all the functions that enable safe flight. This understanding must breakdown assumptions of who (or what) performs the function and where they are situated, how they are performed, and the types of technologies involved. Second, methods do not exist sufficient to rigorously and systematically design and assess transformative changes to general operating and flight rules that impact many stakeholders in the NAS (Finding 2-4 and Recommendation 2-4).

Likewise, the discussion of safety assurance in Chapter 3 highlighted the need for data analytics applicable to identifying emerging trends in aviation safety, learning from the rapidly evolving methods in many other domains. This includes not only methods for analyzing data but

also methods for identifying the data collection mechanisms to build now into transformative technologies and operations to support safety assurance in the decades to come. Unfortunately, research and development of these methods is hindered by lack of representative data sets in the public domain, to the extent that the research communities in data mining, machine learning, and so on, have used other industries as their test cases.

The discussion of organizations in Chapter 4 highlighted how vital culture is to safety. With this comes the question "How to continually mature a safety culture?" This question has two components. First, what is the role of a regulator, such as the FAA AVS, in overseeing an industry organization's safety, and how do they do so? Second, what metrics are appropriate for an organization, and its regulator, to continually monitor and reflect upon, and what processes should be brought to bear for continual learning, adaptation, and maturation of its safety culture?

Finally, Chapter 5's discussion of how to integrate safety across organizations and across all the stages in a product's lifecycle highlight questions in the science underlying safety management. Current methods focus on one organization managing safety in their current operations: How do these transcend to multiple organizations, some interacting deliberately, and some picking up a product or joining in an operation years after it was implemented by others? The corollaries here include how risk can be managed across organizations, and what one organization needs to do right now (e.g., build in data collection mechanisms and capture knowledge) for later organizations to safely implement their developments.

These conceptual questions extend far beyond the research currently conducted by the FAA AVS. Many of them are sufficiently fundamental that research agencies such as the National Science Foundation may have a role, as may the Aeronautics Research Mission Directorate at NASA. Other related agencies, such as efforts to address safety with AI and autonomy by defense research offices, also merit consideration. Thus, the role for the FAA AVS may be to create representative test cases and data sets for the broad national research enterprise to examine, in addition to, or instead of, attempting to single-handedly perform this research in-house.

Appendix A
Case Study Highlighting the Many Considerations in Defining and Implementing General Flight and Operating Rules

To illustrate the many aspects of defining and implementing general flight and operating rules, consider the specifications for a Category II or III instrument approach to land as reflected in the regulations, corresponding specifications to pilots and air traffic controllers, and corresponding practices for defining routes of flight, approach paths, and many other aspects of airports. 14 CFR §91.175 Takeoff and landing under IFR [Instrument Flight Rules][39] specifies that each person operating the aircraft must use a standard instrument approach procedures as defined in published charts, lists the required components required onboard and on the ground as part of an Instrument Landing System (ILS) and specifies the weather minimums in terms of visibility and runway visibility range (RVR) in which these approaches may be conducted. The regulation also authorizes the decision altitude or decision height [above ground] (DA/DH) beyond which the flight crew may continue the flight based on instruments alone, and specifies the conditions required for the flight crew to continue the approach beyond DA/DH, as highlighted in Box A-1.

BOX A-1
Regulations Governing Visual Reference Criteria by Which Pilots May Continue an Instrument Landing Approach Below Decision Altitude/Decision Height

(3) Except for a Category II or Category III approach where any necessary visual reference requirements are specified by the Administrator, at least one of the following visual references for the intended runway is distinctly visible and identifiable to the pilot:

(i) The approach light system, except that the pilot may not descend below 100 feet above the touchdown zone elevation using the approach lights as a reference unless the red terminating bars or the red side row bars are also distinctly visible and identifiable.
(ii) The threshold.
(iii) The threshold markings.
(iv) The threshold lights.
(v) The runway end identifier lights.
(vi) The visual glideslope indicator.
(vii) The touchdown zone or touchdown zone markings.
(viii) The touchdown zone lights.
(ix) The runway or runway markings.
(x) The runway lights.

SOURCE: 14 CFR §91.175.

[39] See https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-91/subpart-B/subject-group-ECFRef6e8c57f580cfd/section-91.175.

This is further detailed from the pilot's point of view in Aeronautical Information Manual (AIM)[40] section 5-4-7 Instrument Approach Procedures, which refers to 14 CFR §91.175 and then elaborates on aircraft-specific aspects of the operation, including approach speeds, maneuvering considerations for bank angle, correcting for wind and pilot technique, rate of descent, and how to expect air traffic control to specify the name of the instrument approach procedure and provide clearance to conduct the approach.

Many of these aspects are also shown in the Instrument Approach Plate for the approach, an example of which is provided in Figure A-1. The approach plate for an approach specifies its routes of flight and vertical profiles, which have been carefully vetted from the perspective of safety (e.g., terrain avoidance) as well as potentially reflecting community concerns such as flight paths mitigating community noise exposure. Pilots are expected to have in front of them the appropriate instrument approach plate throughout the approach, as it establishes a shared structure for everyone operating in the shared airspace, including aircraft that are on the same approach and identifying constraints on this approach that separate it from aircraft on different routes that might intersect or interact.

[40] See https://www.faa.gov/air_traffic/publications/atpubs/aim_html.

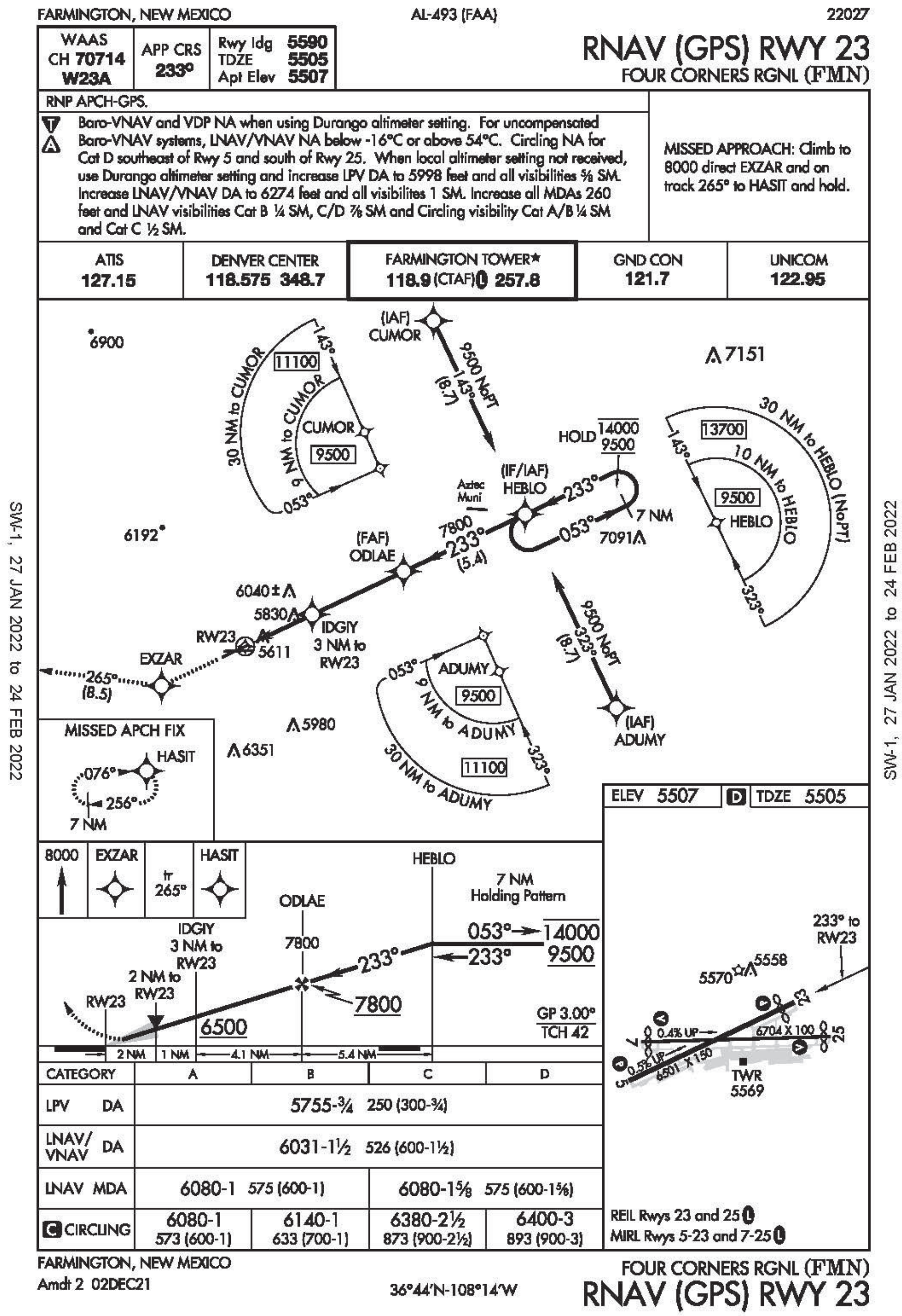

FIGURE A-1 Representative instrument approach plate in AIM.
SOURCE: AIM, 2024.
https://www.faa.gov/air_traffic/publications/atpubs/aim_html/chap5_section_4.html.

Likewise, this operation is detailed from the air traffic controller's point of view in the Federal Aviation Administration (FAA) Order JO 7110.65[41] "Air Traffic Control," which "prescribes air traffic control procedures and phraseology for use by personnel providing air traffic control services. Controllers are required to be familiar with the provisions of this order that pertain to their operational responsibilities and to exercise their best judgment if they encounter situations not covered by it."

In 7110.65, Chapter 4 IFR [Instrument Flight Rules] Section 8 Approach Clearance Procedures details many aspects of the controller's activities during instrument approaches (which must occur under air traffic control). One aspect is the exact phraseology that the air traffic controller must use when clearing an aircraft (verbally, over voice radio) for the approach, shown in Box A-2 to illustrate the specificity with which operations are defined. This section of 7110.65 also details the routing that the controller may/must give to an aircraft to steer it onto the approach, the conditions under which an aircraft may be then considered established on, and "cleared for" the approach, and contingencies for situations such as approaches into airports not served by an active tower or flight service station, missed approaches, and practice approaches by pilots that will not result in the aircraft landing and terminating its flight.

BOX A-2
Exact Phraseology for an Air Traffic Control Clearance to Conduct an Instrument Approach

- *CLEARED (type) APPROACH.*
- *CLEARED APPROACH.*
  (To authorize a pilot to execute his/her choice of instrument approach),
- *CLEARED (specific procedure to be flown) APPROACH.*
  (Where more than one procedure is published on a single chart and a specific procedure is to be flown),
- *CLEARED (*ILS/LDA*) APPROACH, GLIDESLOPE UNUSABLE.*
  (To authorize a pilot to execute an ILS *or an* LDA *approach when the glideslope is out of service)*
- *CLEARED LOCALIZER APPROACH*
  (When the title of the approach procedure contains "or LOC")
- *CANCEL APPROACH CLEARANCE (additional instructions as necessary)*
  (When it is necessary to cancel a previously issued approach clearance)

SOURCE: FAA, 2024.

In addition to these specifications for particular personnel, FAA Order 8260.3D "United States Standard for Terminal Instrument Procedures (TERPS)"[42] serves to "[prescribe] standardized methods for design and evaluating instrument flight procedures (IFPs) in the United States and its territories…. These criteria are predicated on normal aircraft operations and performance."

The TERPS provides detailed criteria for all instrument flight procedures according to the phase of flight and navigation source. The TERPS section 1-4-2 "Nonstandard IFPs" notes that

[41] See https://www.faa.gov/air_traffic/publications/atpubs/atc_html.
[42] See https://www.faa.gov/documentLibrary/media/Order/Order_8260.3D_vs3.pdf.

in some cases the "standard" definition of an instrument flight procedure may not be possible due to "obstacles, navigation information, or traffic congestion." In such cases, an extra step becomes necessary involving a special study: "nonstandard [instrument flight procedures] that deviate from these criteria may be approved, provided they are documented and an equivalent level of safety exists. A nonstandard IFP is not substandard; it has been approved after special study demonstrated that no derogation of safety is involved."

When defining a specific instrument approach, the TERPS require defining the geographic space within which the approach can be proven to be clear of terrain and through which other routes cannot cross, as shown in Figure A-2. The horizontal path may be somewhat offset from a straight-line with the runway for reasons such as terrain or other obstacles on the straight-line course, or directionality in the navigation aids. The lower bound of the vertical profile must provide sufficient clearance from terrain in the initial, intermediate and final approach segments; the upper bound then defines where other air traffic may be allowed, including other aircraft in the traffic pattern above and around the airport. The TERPS also call out important references back to 14 CFR §91—for example, TERPS section 2-1-10 notes, "Do not establish speed restrictions that require an aircraft to exceed the restrictions in 14 CFR Part 91.117 (a) and (c)."

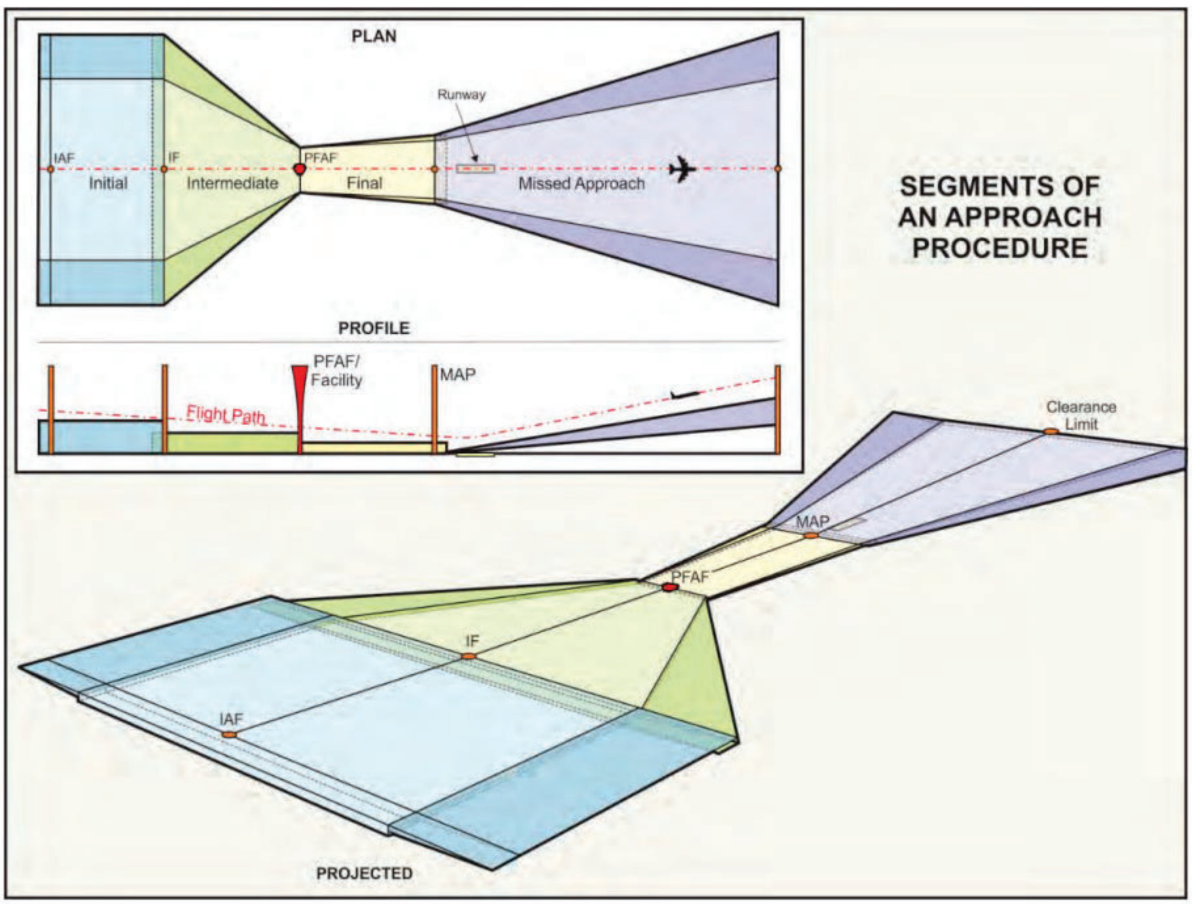

FIGURE A-2 Segments of an approach procedure.
SOURCE: TERPS, 2018.

The TERPS define the geographic space also based on the flight performance assumed of current vehicles. For example, section 2-6 "Final Approach" notes that in situations where precision vertical navigation is possible, "Use a standard 3.00 degree [glide path angle] GPA where possible. GPAs greater than 3.00 degrees but not more than the maximum [defined relative to aircraft speed, ranging from 3.10 for the fastest aircraft to 6.40 for the slowest] are authorized without approval when needed."

These examples highlight the extent to which instrument approach procedures, and other instrument procedures and routes of flight, are defined within an elaborate, carefully constructed paradigm that structures the procedure and its route of flight to address many safety concerns. In this context, a request by an aircraft operator for a different procedure can be quickly examined by stepping through the analysis process defined by the TERPS if it complies with deeply embedded assumptions about "normal aircraft operations and performance." However, requests for new procedures accommodating different vehicles with different performance may face two difficulties: (1) procedurally, they may require separate, special assessment and approval is not guaranteed, and (2) pragmatically, different vehicle performance may correspond to different flight profiles not covered by the TERPS, and potentially conflicting with other routes. For example, an aircraft designed for short, lower-altitude flights may be best suited by a steep descent angle on final approach; however, such a steep descent may conflict with the routes normally assumed free for aircraft crossing the airfield to join the traffic pattern.

Appendix B
Public Workshop and Meeting Agendas

PUBLIC WORKSHOP #1

March 20, 2023

9:00–9:10 Opening remarks from the study sponsor and the study chair
The speakers briefly discuss the study tasks and workshop goals.

9:10–9:30 Icebreaker activity
Workshop facilitators from the Aerospace Corporation lead the activity.

9:30–10:00 Overview of first report findings and an introduction of case studies for examination
The study chair briefly shares the key findings from the committee's first report and discusses step changes in commercial aviation safety, which will serve as a group exercise for examining safety cases to allow for those safety changes in the National Airspace System (NAS).

10:05–11:55 Facilitated breakout group discussions on safety cases
Aerospace Corp facilitates small group discussions on the reasonable safety cases for allowing such new step changes into the NAS.

12:00–12:30 Cross-share breakout team insights
Workshop participants reconvene to share insights on the safety case discussions.

12:30–1:00 Break

1:00–3:25 Facilitated breakout group discussions
Group participants will be remixed for resumed facilitated discussions.

3:30–4:00 Cross-share breakout team insights
Workshop participants reconvene to share insights on the safety case discussions.

4:00–4:30 Enterprise modeling discussion led by Aerospace Corp

4:30–5:00 Concluding discussions led by the study chair

5:00	Workshop adjourns

PUBLIC WORKSHOP #2

August 29, 2023

8:30–8:40	Opening remarks from the study sponsor and the study chair *The speakers briefly discuss the study tasks and workshop goals.*
8:40–10:15	Innovator presentations *Presentations from SkyGrid, Wisk, and XWing highlighting new or unusual challenges in establishing a safety case that their innovation is facing.*
10:15–10:30	Break
10:30–12:00	Facilitated breakout group discussions on safety cases *Aerospace Corp facilitates small group discussions based on the innovator presentations.*
12:00–12:30	Break
12:30–1:00	Cross-share breakout team insights *Workshop participants reconvene to share insights on the safety case discussions.*
1:00–3:25	Facilitated breakout group discussions *Group participants will be remixed for resumed facilitated discussions.*
3:30–4:00	Cross-share breakout team insights *Workshop participants reconvene to share insights on the safety case discussions.*
4:00–5:00	Concluding discussions led by the study chair
5:00	Workshop adjourns

VIRTUAL MEETING ON REGULATOR SAFETY CULTURE

June 14, 2023

SESSION 1—OPEN
PRESENTATION ON REGULATOR SAFETY CULTURE

2:00–3:30	**Mark Fleming,** *Professor,* Saint Mary's University

SESSION 2—CLOSED
COMMITTEE DELIBERATION

3:30–4:00 Committee discussion on regulator safety culture presentation

VIRTUAL MEETING ON NEW ENTRANT CERTIFICATION PROCESSES

July 13, 2023

SESSION 1—OPEN
BRIEFINGS FROM KEY STAKEHOLDERS

1:00–1:45 FAA Approach to New Technologies
James Williams, *Chief Executive,* JHW Unmanned Solutions LLC

1:45–3:30 FAA Panel Discussion on Certification Processes for New Entrants
Angela Anderson, *Acting Deputy Executive Director, Office of Rulemaking*, FAA

David Hempe, *Deputy Director, Aircraft Certification Service,* FAA

Jeffery Vincent, *Executive Director for the Unmanned Aircraft Systems,* FAA

Robert Ruiz, *Acting Deputy Executive Director*, *Flight Standards Service*, FAA

SESSION 2—CLOSED
COMMITTEE DELIBERATION

3:30–5:30 Committee discussions on speaker presentation and panel discussion

VIRTUAL MEETING ON THE AVS 2022 SAFETY CULTURE SURVEY

September 8, 2023

SESSION 1—OPEN
BRIEFINGS FROM FAA

2:00–3:30 **Kylie Key,** *Office of Accident Investigation and Prevention,* FAA

Genoveva Martin, *Special Assistant, Office of Accident Investigation and Prevention,* FAA

SESSION 2—CLOSED
COMMITTEE DELIBERATION

3:30–4:00 Committee discussions on speaker presentations

VIRTUAL MEETING ON THE AVS 2022 SAFETY CULTURE SURVEY

March 11, 2024

SESSION 1—OPEN
BRIEFINGS FROM FAA

3:30–4:30 **Kylie Key,** *Office of Accident Investigation and Prevention,* FAA

Genoveva Martin, *Special Assistant, Office of Accident Investigation and Prevention,* FAA

Katherine Murphy, *Safety Culture Program Manager, Office of Accident Investigation and Prevention,* FAA

Appendix C
Study Committee Biographical Information

Amy R. Pritchett (*Chair*) is a professor and the head of the Department of Aerospace Engineering at The Pennsylvania State University. Previously, she was on the faculty of the Schools of Aerospace Engineering and Industrial and Systems Engineering at the Georgia Institute of Technology, and she served via the Intergovernmental Personnel Act as the director of NASA's Aviation Safety Program for 2 years. Her research focuses on the intersection of technology, expert human performance, and aerospace operations, with a particular focus on designing to support safety. Her research topics have included autonomous flight and unmanned aerial vehicles, vehicle dynamics and controls, and vehicle systems engineering. She recently served as the editor-in-chief of the *Journal of Cognitive Engineering and Decision Making*. She has served on many National Academies' committees, including as the chair of the Committee for a Study of FAA Air Traffic Controller Staffing and as a member of the Committee on Assessing the Risks of Unmanned Aircraft Systems (UAS) Integration and the Committee of the Federal Aviation Administration Research Plan on Certification of New Technologies into the National Airspace System. In addition, she served as a member of the National Academies' Aeronautics and Space Engineering Board. She is a licensed pilot in airplanes and sailplanes. Dr. Pritchett earned an Sc.D., S.M., and S.B. in aeronautics and astronautics from the Massachusetts Institute of Technology.

Cody H. Fleming is an associate professor with the Department of Mechanical Engineering at Iowa State University. Prior to Iowa State, he had joint appointments in systems engineering and mechanical and aerospace engineering at the University of Virginia (UVA). He was a founding member of the interdisciplinary Link Lab for Cyber-physical Systems at UVA. He also has a wide range of interest ranging from dynamics and control, system safety, autonomy and planning, system integration, and safety by design. Dr. Fleming has a bachelor's degree in engineering from Hope College, a master of engineering in civil and environmental engineering from the Massachusetts Institute of Technology (MIT), and a doctor of philosophy degree in aeronautics and astronautics from MIT.

R. John Hansman, Jr., is the T. Wilson Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT), where he is the director of the MIT International Center for Air Transportation. He conducts research in the application of information technology in operational aerospace systems. He has more than 5,800 hours of pilot in-command time in airplanes, helicopters, and sailplanes, including meteorological, production, and engineering flight test experience. He chairs the U.S. Federal Aviation Administration (FAA) Research Engineering and Development Advisory Committee and other national and international advisory committees. He is a member of the U.S. National Academy of Engineering, is a fellow of the American Institute of Aeronautics and Astronautics (AIAA), and has received numerous awards including

the AIAA Dryden Lectureship in Aeronautics Research, the Air Traffic Control Association Kriske Air Traffic Award, a Laurel from Aviation Week & Space Technology, and the FAA Excellence in Aviation Award. He is currently a member of the Board on Army Science and Technology and the Committee on Aviation Safety Assurance at the National Academies. He holds a Ph.D. in physics, meteorology, and aeronautics from MIT.

Christopher A. Hart is the founder of Hart Solutions LLP, which specializes in improving safety in a variety of contexts. He is the chair of the Washington Metrorail Safety Commission, a three-jurisdictional agency (Maryland, Virginia, and Washington, DC) that oversees the safety of the Washington area subway system. In 2019 he was asked by the Federal Aviation Administration (FAA) to lead the Joint Authorities Technical Review that was created to bring together the certification authorities of 10 countries, as well as NASA, to review FAA's process for certifying the flight control systems of the Boeing 737 Max and make recommendations for improvement. In 2021 he was selected for the Board of the Joint Commission, a nongovernmental organization that accredits hospitals, to help improve health care safety. He was invited in 2021 to be on the FAA Management Advisory Council. After an Uber test vehicle struck and killed a pedestrian in Tempe, Arizona, in 2018, he was among the experts that were engaged to recommend how to safely resume street testing. From 2009 until 2018 Mr. Hart was the chair, vice chair, and a member of the National Transportation Safety Board (NTSB), having been nominated by President Obama. He was previously a member of NTSB from 1990 until 1993, having been nominated by (the first) President Bush. Mr. Hart has a law degree from Harvard Law School and master's and bachelor's degrees (magna cum laude) in aerospace engineering from Princeton University. He is a pilot with a Cessna Citation SIC Type Rating.

Margaret T. Jenny is a retired president of RTCA, Inc., a private, not-for-profit corporation dedicated to the forging of wide-ranging, consensus-based recommendations in aviation policy, technology, and modernization. Prior to joining RTCA, she served as the chief executive officer of MJF Strategies, LLC, an aviation consulting firm; the vice president of corporate business development at ARINC; the director of airline business and operations analysis for US Airways; and the technical director at The MITRE Corporation. She served as the 2016 president of the Aero Club of Washington. She was a member of the National Academies' Committee on the Federal Transportation R&D Strategic Planning Process; the Committee on Review of the National Transportation Science and Technology Strategy; and the Aeronautics Research and Technology Roundtable. She is a member of the Board of Directors of the Center for the Advancement of Science in Space, which manages the International Space Station National Laboratories. Ms. Jenny earned her M.S. in computer science from American University.

Paul McCarthy served as the chair of the Air Line Pilots Association and the International Federation of Air Line Pilots' Associations from June 1990 to December 2012. Prior to that experience he was a captain for Delta Airlines from January 1973 to 2004. His expertise is sought in aviation flying and safety issues and he has testified before the House and Senate committees on these topics. Captain McCarthy holds a bachelor's degree in accounting from the University of Notre Dame and a J.D. from Suffolk University Law School.

William B. Rouse is an author, researcher, and entrepreneur focused on understanding and transforming complex organizational systems in health care, education, energy, transportation, and

national security. In these areas, he has consulted with more than 100 large and small enterprises in the private, public, and nonprofit sectors, where he has worked with several thousand executives and senior managers. His use of computational models to address these challenges has been widely recognized. Dr. Rouse founded and led several technology companies including Curis Meditor, LLC, Enterprise Support Systems, Inc., and Search Technology, Inc. He has served on the faculties of Georgetown University, Georgia Institute of Technology, University of Illinois, Delft University of Technology, Stevens Institute of Technology, and Tufts University. He is a professor emeritus and the former chair of the School of Industrial and Systems Engineering at Georgia Tech. Among many advisory roles, he has served as the chair of the Committee on Human Factors (now Board on Human-Systems Integration) of the National Academies, a member of the advisory committee for the Division of Behavioral and Social Sciences and Education of the National Academies, a member of the U.S. Air Force Scientific Advisory Board, and a member of the Department of Defense Senior Advisory Group on Modeling and Simulation. He has been designated a lifetime national associate of the National Research Council and the National Academies. Dr. Rouse is a member of the National Academy of Engineering and has been elected a fellow of four professional societies: Institute of Electrical and Electronics Engineers, the International Council on Systems Engineering, the Institute for Operations Research and Management Science, and the Human Factors and Ergonomics Society. Dr. Rouse received his B.S. from the University of Rhode Island and his S.M. and Ph.D. from the Massachusetts Institute of Technology.

Nadine B. Sarter is a professor in the Department of Industrial and Operations Engineering, a member of the core faculty at the Robotics Institute, and the director of the Center for Ergonomics at the University of Michigan. She is also the director of the Occupational Safety Engineering and Ergonomics Program at the University of Michigan Center for Occupational Health and Safety. Her research in cognitive systems engineering focuses on the design and evaluation of tasks, protocols, and interfaces that support safe and effective human-automation/robot interaction and human–machine teaming. Specific research interests include contributors to and performance effects of system complexity, haptic and multimodal display design, transparency and operator trust in highly autonomous systems, adaptive function allocation, attention and interruption management, and the design of decision aids for high-tempo operations. She has conducted her work in a wide range of application domains, most notably commercial and military aviation (both manned and unmanned operations), space, medicine, military operations, and the automotive industry. She serves as the associate editor for *Human Factors* and is a member of the editorial boards of the *Journal of Cognitive Engineering and Decision Making* and the *International Journal of Aviation Psychology*. She is a fellow of the Human Factors and Ergonomics Society and a member of the American Institute of Aeronautics and Astronautics, the Association for Computing Machinery, and the Society for Human Performance in Extreme Environments. She is an affiliate member of the American Psychological Association Division 21 (Applied Experimental and Engineering Psychology). She is a member of the National Academy of Engineering, a member of the 2017–2018 Cohort of the UM Rudi Ansbacher Women in Academic Medicine Leadership Scholars Program, and a member of the Human Factors and Ergonomics Society fellow selection committee. She was a participant in the Human Performance Expert Panel to Inform the Air Force Strategy 2030 and a member of the National Academies' (Board on Human-Systems Integration) Expert Panel on FAA Staffing Issues. She received an M.S. in applied and experimental psychology and a B.S. in psychology from the University of Hamburg in

Germany in 1983 and 1981, respectively. She received a Ph.D. in industrial and systems engineering from The Ohio State University in 1994.

Ashok N. Srivastava is the senior vice president and the chief data officer at Intuit. He is responsible for setting the vision and direction for artificial intelligence and data across Intuit to power prosperity across the world. He is an adjunct professor at Stanford University, a member of the Board of Directors of the University of Colorado Foundation, and a fellow of the Institute of Electrical and Electronics Engineers (IEEE), the American Association for the Advancement of Science, and the American Institute of Aeronautics and Astronautics (AIAA). Previously, he was the vice president of big data and artificial intelligence systems and the chief data scientist at Verizon. His global team focused on building new revenue-generating products and services powered by big data and artificial intelligence. He was also the editor-in-chief of the AIAA *Journal of Aerospace Information Systems*. Previously, he led advanced technology programs in aerospace, space systems, and earth and space sciences at NASA. He is the author of more than 100 research articles in data mining, machine learning, and text mining, and has edited the book *Text Mining: Classification, Clustering, and Applications*. He has won numerous awards, including the IEEE Computer Society Technical Achievement Award for "pioneering contributions to intelligent information systems," the NASA Exceptional Achievement Medal for contributions to state-of-the-art data mining and analysis, the NASA Honor Award for Outstanding Leadership, the NASA Distinguished Performance Award, several NASA Group Achievement Awards, the Distinguished Engineering Alumni Award from the University of Colorado Boulder, the IBM Golden Circle Award, and the Department of Education Merit Fellowship. Mr. Ashok holds a Ph.D. in electrical engineering from the University of Colorado Boulder.

Kathleen M. Sutcliffe is a Bloomberg Distinguished Professor with appointments in the Carey Business School, the School of Medicine (Anesthesia and Critical Care Medicine), the School of Nursing, the Bloomberg School of Public Health, and the Armstrong Institute for Patient Safety and Quality at Johns Hopkins University. She is also a professor emeritus of management and organization at the University of Michigan Ross School of Business. Her research program has been devoted to investigating how organizations and their members cope with uncertainty and how organizations can be designed to be more reliable and resilient. She has investigated organizational safety, high reliability, and resilience practices in oil and gas exploration and production, chemical processing, steel production, wildland firefighting, and in health care. She has published widely in management and organization theory and health care and has co-authored/co-edited seven books. She serves on the editorial boards of several journals and participated previously in the National Academies' study investigating workforce resilience at the Department of Homeland Security. She has consulted with the leadership teams of numerous companies, including Goldman Sachs, Georgia Pacific, Marathon Oil, and ThyssenKrupp. She is a fellow of the Academy of Management. She received her doctor of philosophy in organization theory and organizational behavior from The University of Texas at Austin.

Alyson G. Wilson is the senior associate vice chancellor for research at North Carolina State University (NC State). She is also a professor in the Department of Statistics, the principal investigator for the Laboratory for Analytic Sciences, and the director of the Data Science Initiative. She is a fellow of the American Statistical Association and the American Association for the Advancement of Science. Her research interests include statistical reliability, Bayesian

methods, and the application of statistics to problems in defense and national security. Prior to joining NC State, she was a research staff member at the Institute for Defense Analyses Science and Technology Policy Institute in Washington, DC (2011–2013); an associate professor in the Department of Statistics at Iowa State University (2008–2011); a technical staff member in the Statistical Sciences Group at Los Alamos National Laboratory, where she continues as a guest scientist; and a senior statistician and an operations research analyst with Cowboy Programming Resources (1995–1999). She is the winner of the American Statistical Association Section on Statistics in Defense and National Security Distinguished Achievement Award (2018), NC State Alumni Association Outstanding Research Award (2017), and the Army Wilks Memorial Award (2015). In addition to numerous publications, she has co-authored a book, *Bayesian Reliability*, and has co-edited two other books, *Statistical Methods in Counterterrorism: Game Theory, Modeling, Syndromic Surveillance* and *Biometric Authentication and Modern Statistical and Mathematical Methods in Reliability*. She has participated in seven previous National Academies' studies, including the Committee on Methodological Improvements to the Department of Homeland Security's Biological Agent Risk Analysis. Dr. Wilson received her Ph.D. in statistics from Duke University.